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Effect of Catalysts and pH on Strength of Resin-Bonded Plywood[1]

By *Gordon M. Kline, Frank W. Reinhart, Royden C. Rinker, and Nicholas J. DeLollis*

The effects of various catalysts used to cure the resinous adhesives on the strength properties of plywood were investigated, particularly with regard to the degree of acidity developed by the catalysts in the resin film and in the plywood. The flexural, impact, and shear strengths, both initially and after aging, of birch plywoods bonded with urea-formaldehyde and phenol-formaldehyde resins definitely decrease as the acidity of the plywood increases, as evidenced by a decrease in pH. Only in the case of plywood bonded with casein and urea-formaldehyde resins had the deterioration at the bond progressed sufficiently in the roof-aging tests to make it impossible to carry out strength tests because of delamination. A correlation between decrease in strength on aging of plywood bonded with alkali-catalyzed phenolic acid and increase in alkalinity of the panel was observed. Because of the different absorption capacities of the phenolic resins for acids and alkalies, it is not possible to predict the pH of the plywood panel from the pH of the resin film.

The susceptibility of birch wood, itself, to attack by acids and alkalies was determined in order to better understand the mechanism of the deterioration of resin-bonded plywood. A marked decrease in strength occurred when the pH of the wood was lowered below 2.0. In the range between pH 2.0 and 2.5, strong acids, such as hydrochloric and sulfuric, had a more pronounced deteriorating effect than weak acids, such as hypophosphorous and nitranilic. A marked decrease in strength of the birch also occurred when the pH was raised to 8.8 by the absorption of an alkali, tetraethanolammonium hydroxide.

I. Introduction

The increased use of resin-bonded plywood for structural parts of aircraft has made it necessary to determine the effect of various chemical properties of the resins on the strength properties of the resin bonds. Information of this nature is needed to utilize the materials properly in building satisfactory aircraft and to evaluate the causes of failure. Determination of the effect of acid and alkaline catalysts on the strength and aging properties of various types of resin bonds is one important phase of this work. This report presents the results of an investigation which was made to determine these relationships. Some of the data obtained in the early stages of the work were included in a preliminary report issued in 1943 [1].[2]

The degree of acidity or hydrogen-ion concentration can conveniently be reported as a pH

[1] NACA Technical Note No. 1161.

[2] Figures in brackets indicate the literature references at the end of this paper.

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value which approximately is the logarithm of the reciprocal of the gram ionic hydrogen equivalents per liter; that is, $pH = \log 1/H^+$ per liter. Water has a concentration of H^+ ion of 10^{-7} and of OH^- ion of 10^{-7} moles per liter or a pH value of 7, and is said to be neutral in reaction. The presence of an acid in a water solution increases the concentration of hydrogen ions. Hence the concentration of hydrogen ions in an acid solution becomes 10^{-6} or 10^{-5}, or greater, and the pH value is less than 7. The presence of an alkali in a water solution increases the concentration of hydroxyl ions and decreases that of the hydrogen ions. Hence the concentration of hydrogen ions in an alkaline solution becomes 10^{-8}, 10^{-9}, or less, and the pH value is greater than 7. The product of the hydrogen ion concentration and the hydroxyl-ion concentration is always equal to 10^{-14} in aqueous medium at 25° C. The pH value has been used throughout this report to indicate the degree of acidity of the various specimens.

The two most commonly used types of bonding agents in the manufacture of resin-bonded plywood are the phenol-formaldehyde and the urea-formaldehyde resins. Both types are cured either by the "hot-set" or the "cold-set" method. Since the demarcation between "cold-set" and "hot-set" bonding resins has not been definitely established in the industry, the resins used in this project were classified according to the temperature required to cure the resin in a commercially practical period of time, as follows:

Class R.—These resins do not require a higher degree of heat for curing than that available at ordinary room or factory conditions.

Class M.—These resins require a degree of heat greater than that available at room or factory conditions, but not over 160° F (71° C).

Class H.—These resins require a temperature greater than 160° F (71° C).

To obtain a satisfactory degree of cure of class *R* and some class *M* resins, it is necessary with most of the commercial resins to use very active catalysts. One of the most active catalysts for curing these types of resins is the hydrogen ion, which is usually expressed in terms of pH units when the concentration is less than 1 molar.

It is an established fact that wood deteriorates rapidly in acidic media. It is also known that urea-formaldehyde resins are not as resistant to acid condition as are phenolic resins [2–7]. The work reported herein was designed to determine the effects of various catalysts and the pH of the resin bond on the strength properties of the resin-wood composite since the failures may be in the resin, in the wood, or in both resin and wood. It should be noted, however, that the acid conditions in the resin-bonded birch panels tested are attributable to the ingredients in the resin-glue mixtures and not to the wood or any extraneous source.

This investigation, conducted at the National Bureau of Standards, was sponsored by and conducted with financial assistance from the National Advisory Committee for Aeronautics.

II. Materials

A group of adhesives which are being used to a great extent in the manufacture of resin-bonded plywood aircraft was selected for this work. These included urea-formaldehyde, phenol-formaldehyde, resorcinol-formaldehyde, furane, and unsaturated polyester resins and casein. The commercial designations and the manufacturers of the resins, and the classification of the various resins and resin-catalyst mixtures on the basis of the temperature required for curing, are given in table 1.

Birch wood was used in the tests because it is the type most commonly employed in the manufacture of aircraft grade plywood in this country. Other woods were not investigated inasmuch as the primary objective of the investigation was the study of deteriorative effects characteristic of various resin-catalyst systems.

The test panels were made with sliced birch veneers carefully selected for straightness of grain and having an average thickness of 0.01 in. The thin veneers were used to obtain a higher resin content than that normally used in aircraft plywood. As the acidic conditions result from the resin, a high resin content would be expected to magnify the effect of the pH on the strength properties of the composite.

For the tests on the effect of the catalysts on the wood alone, sliced birch veneers 0.1 in. in thickness and specially selected for straightness of grain were used.

TABLE 1.—*Description of resins and resin-bonded birch panels*

Commercial designation of resin	Manufacturer	Catalyst added to resin	Classification [a]	Conditions of cure: Temperature	Conditions of cure: Time	Density, average	Resin content of panels, average	pH: Resin film	pH: Resin-bonded birch plywood: Unaged	pH: Resin-bonded birch plywood: Oven-aged	pH: Resin-bonded birch plywood: Oven-fog-aged	pH: Resin-bonded birch plywood: Roof-aged
UREA-FORMALDEHYDE RESINS												
				°*F*	*hr : min*	*g/cm³*	*Percent*					
Uformite 430	Resinous Products and Chemical Co.	10% Ammonium chloride.	*R*	Room	24 : 00	0.91	33	1.2	1.9	------	------	------
Do	do	10% "Z"	*R*	do	24 : 00	.91	37	1.6	2.0	2.1	2.6	------
Do	do	10% "Y"	*R*	do	24 : 00	.94	40	1.8	2.4	2.5	3.3	------
Plaskon 201-2	Plaskon Div., Libbey-Owens-Ford Glass Co.	2% "A"	*R*	do	24 : 00	.93	37	2.6	3.2	3.4	3.3	3.9
Casco 5	Casein Company of America	5% "AA"	*R*	do	24 : 00	1.02	37	3.2	3.4	3.1	3.6	
Plaskon 250-2	Plaskon Div., Libbey-Owens-Ford Glass Co.	Incorporated with resin.	*R*	do	24 : 00	0.88	34	3.4	3.6	3.4	3.6	3.8
Plaskon 107	do	7% B-7	*H*	300	0 : 8	.96	31	4.0	3.8	4.0	4.0	4.5
Uformite 500	Resinous Products and Chemical Co.	None	*H*	300	0 : 15	.95	33	7.2	5.5	5.2	5.3	4.4
Casco 5	Casein Company of America	do	*H*	300	0 : 30	.98	35	7.5	5.7	6.0	5.9	3.9
Uformite 430	Resinous Products and Chemical Co.	do	*H*	300	0 : 6	1.00	33	7.7	4.6	4.6	4.7	3.6
UREA-RESORCINOL-FORMALDEHYDE RESINS												
Uformite 500	Resinous Products and Chemical Co.	20% Q 107; 0.7% Q 87	*M*	150	3 : 00	0.99	35	2.9	5.1	4.2	4.7	4.0
Plaskon 700-2	Plaskon Div., Libbey-Owens-Ford Glass Co.	16% Modifier	*M*	Room 150	20 : 00 3 : 00	.96	35	4.8	4.6	4.6	4.6	4.1
PHENOL-FORMALDEHYDE RESINS												
Durez 12041	Durez Plastics and Chemicals, Inc.	10% 7422	*M*	150	24 : 00	0.97	36	1.4	1.8	1.8	1.9	2.6
Durez 11427	do	10% 7422	*M*	150	24 : 00	1.04	39	1.4	1.8	1.8	1.9	2.6
Catabond 590	Catalin Corp	11% Hydrochloric acid (27.8%).	*M*	Room 150	24 : 00 1 : 00	0.90	37	1.6	1.7	2.0	2.3	3.1
Catabond 200 CZ	do	do	*M*	Room 150	24 : 00 1 : 00	.91	37	1.6	1.8	2.1	2.4	2.8
Bakelite XC-3931	Bakelite Corp	3% XK-2997	*M*	Room 150	24 : 00 2 : 00	.90	31	1.9	2.7	2.8	3.0	3.3
Bakelite XC-11749	do	45% XK-11753	*R*	Room	24 : 00	.87	31	1.9	3.1	3.0	3.3	3.3
Catabond 590	Catalin Corp	None	*H*	300	0 : 30	.94	29	3.8	3.6	3.7	3.6	3.4
Bakelite XC-3931	Bakelite Corp	do	*H*	300	0 : 30	.97	35	5.5	4.5	4.7	4.5	3.5
Bakelite XC-11749	do	do	*H*	300	0 : 45	.93	42	5.9	3.9	3.9	3.9	3.7
Catabond 200 CZ	Catalin Corp	do	*H*	300	0 : 30	1.00	31	6.6	4.6	4.6	4.7	4.3
Cascophen LT-67	Casein Company of America	8% M-18	*M*	150	24 : 00	0.95	37	7.5	6.4	6.2	6.2	5.0
Durez 12041	Durez Plastics and Chemicals, Inc.	None	*H*	300	0 : 30	.97	33	8.2	5.0	5.0	5.0	4.6
Bakelite BC-17540	Bakelite Corp	15% BC-17545	*M*	150	24 : 00	.94	21	9.2	7.3	------	7.3	------
Tego film	Resinous Products and Chemical Co.	None	*H*	300	0 : 10	.80	20	9.5	8.2	------	------	
Amberlite PR-14	do	Incorporated with resin.	*H*	300	0 : 12	.85	23	9.8	8.4	8.3	8.0	6.2
RESORCINOL-FORMALDEHYDE RESINS												
Durez 12490	Durez Plastics and Chemicals, Inc.	30% Formaldehyde (37%).	*R*	Room	24 : 00	0.81	26	5.7	4.8	5.2	5.3	4.9
Penacolite G-1131	Pennsylvania Coal Products Co.	20% G-1131 B	*R*	do	24 : 00	.89	26	6.0	5.1	------	5.2	4.1
Bakelite XC-17613	Bakelite Corp	20% XK-17618	*M*	150	24 : 00	.97	28	6.2	4.8	------	4.6	
Amberlite PR-75 B	Resinous Products and Chemical Co.	22% P-79	*M*	150	24 : 00	.94	32	6.4	5.4	------	4.8	------
Penacolite G-1124	Pennsylvania Coal Products Co.	25% G-1124-B	*R*	Room	24 : 00	.94	33	7.0	5.1	5.2	5.4	4.5
Durite S-3026	Durite Plastics, Inc.	16% 3026A	*R*	do	24 : 00	.86	22	7.5	6.3	------	6.0	------

See footnote at end of table.

Table 1.—*Description of resins and resin-bonded birch panels*—Continued

Commercial designation of resin	Manufacturer	Catalyst added to resin	Classification [a]	Conditions of cure		Density, average	Resin content of panels, average	pH				
				Temperature	Time			Resin film	Resin-bonded birch plywood			
									Unaged	Oven-aged	Oven-fog-aged	Roof-aged
PHENOL-RESORCINOL-FORMALDEHYDE RESIN												
				°*F*	*hr : min*	*g/cm*^{3}	*Percent*					
Durez 12533	Durez Plastics and Chemicals, Inc.	100% 12534 B	*M*	150	24 : 00	0.94	38	6.6	5.1	5.5	5.4	5.0
FURANE RESIN												
Resin X	Plastics Industries Technical Institute.	5% Z-1A	*R*	Room	24 : 00	1.00	28	1.7	2.2	------	2.3	2.6
CASEIN GLUE												
Aircraft joint P glue	Casein Company of America	None	*R*	Room	24 : 00	0.88	34	12.0	8.4	7.8	8.0	------
UNSATURATED POLYESTER RESINS												
Laminac	American Cyanamid Co	1% Benzoyl Peroxide	*H*	{125 300	0 : 30 0 : 5	0.83	26	2.4	5.7	3.9	3.8	3.4
Do	do	1% Lauroyl Peroxide	*H*	{125 300	0 : 30 0 : 5	.81	24	2.8	4.0	4.0	4.0	3.5
MR-17-A2	Marco Chemical Co	3% Benzoyl Peroxide	*H*	230	2 : 00	1.05	41	3.2	3.7	3.9	2.7	3.5
MR-17-B1	do	do	*H*	230	2 : 00	1.01	39	3.4	3.2	3.3	2.6	3.5
Plaskon 900	Plaskon Div., Libbey-Owens-Ford Glass Co.	2% Benzoyl Peroxide	*M*	150	24 : 00	0.94	29	3.3	3.8	------	3.4	------
CR-39	Pittsburgh Plate Glass Co	5% Benzoyl Peroxide	*H*	160	72 : 00	1.21	51	5.1	3.9	2.7	2.7	3.1

[a] The resins are classified according to the temperature required to cure the resin. Class *R* includes those which cure quickly at room temperature. Class *M* includes those which require a temperature above room temperature but not over 160° F. to cure. Class *H* includes those which require a temperature above 160° F. to cure.

III. Preparation of Test Panels

The resin glues were prepared according to directions received from the manufacturers and were applied to the birch veneers by means of rollers. This method produced resin films of uniform thickness on both sides of the veneers. The veneers coated with the class *H* resins were suspended from a drying rack and allowed to dry about 20 hours before the assembling and pressing. The veneers coated with the class *R* and class *M* resins were assembled and pressed immediately after coating. Each panel consisted of eight birch veneers arranged with the grain of plies one, three, six, and eight parallel to one another and with the grain of plies two, four, five, and seven perpendicular to the face plies.

In the early stages of the investigation the test panels were pressed at approximately 100 lb/in.^{2}, but this produced panels varying considerably in thickness and density. To obtain more uniform panels, stops 9 by 1 in. for use between the press platens were ground to a thickness of 0.075 ± 0.001 in., and the platens were ground to a flatness of 0.0001 in. A load of 10 tons was applied to the platens.

The birch veneers used in each panel were conditioned by storage at 77° F (25° C) and 50-percent relative humidity, and were weighed before the resin coating was applied. The completed test panel was also conditioned and weighed. The resin content (in percent) of the test panel was then calculated by means of the equation

$$\frac{\text{wt of test panel} - \text{wt of conditioned veneers}}{\text{wt of test panel}} \times 100.$$

Three panels were prepared with each resin or resin-catalyst mixture. The conditions used to cure the panels, the average densities, and the average resin contents are given in table 1.

IV. Testing Procedures

1. Aging

Each test panel was cut into quarters and treated as follows:

One quarter section was not subjected to any aging treatment.

One quarter section was exposed continuously in Washington, D. C., (on the roof of the Industrial Building, National Bureau of Standards) on racks at an angle of 45°, facing south for 1 year unless otherwise noted.

One quarter section was heated in a forced-draft oven at 176° F (80° C) for 40 hours.

One quarter section was subjected to a continuous oven-fog cyclic accelerated aging test. The cycle in this test consisted of the following:

Exposure period	Temperature		Relative humidity	Apparatus
hr	*°F*	*°C*	*Percent*	
2	77	25	100	Fog cabinet.
2	149	65	5	Forced-draft oven.
2	77	25	100	Fog cabinet.
18	149	65	5	Forced-draft oven.

The sections were exposed for a total of 200 hours in the oven and 40 hours in the fog cabinet.

This latter test is a modification of the accelerated weathering test described in Federal Specification L–P–406a, Method 6021. Heating in an oven at 149° F (65° C) was substituted for the irradiation under the sunlamp prescribed in Method 6021 because the effect of the ultraviolet light would be expected to be negligible in the breakdown of the resin layer in plywood. The temperature to which the specimens are exposed is approximately 149° F (65° C) in both tests. The data in table 2 show that the decreases in flexural strength resulting from exposure of plywood specimens to the two tests, respectively, are practically identical.

2. Determination of pH

A thin film of the resins of class R and class M was cast on glass and allowed to dry for 20 hours at a temperature of 70° to 79° F (21° to 26° C). The resin film was then removed from the glass and ground to a fineness of 40 mesh. Two grams of the powdered resin were suspended in 10 milliliters of distilled water and the pH of the suspension was measured by means of a glass electrode after 15 minutes, and after 24, 48, 72, and 96 hours, or until the values were constant to within 0.05 pH unit.

Films were prepared from the class H resins by casting them upon a glass plate, using a knife blade to remove excess resin and make the thickness of the coating 0.02 in. or less. The cast films were placed in a circulating-air oven at 149° F (65° C) until examination showed that most of the solvent had evaporated; this process required about 4 hours except in the case of Plaskon 107, which was cured after 3 hours at 149° F (65° C) and was not subjected to any further heating. This drying was followed by a cure in the oven at 300° F (149° C) until the films were hard and brittle, the latter operation requiring about 30 minutes. The hard, brittle films were pulverized in a small rock-crushing mortar and passed through a 40-mesh screen. The pH values of the powdered films were measured in the same manner as those of the class *R* and the class *M* films.

TABLE 2.—*Effect of oven-fog and sunlamp-fog aging tests (240 hours) on flexural strength of resin-bonded birch plywood panels*

Commercial designation of resin	Catalyst added to resin	Unaged panel		Oven-fog-aged panel		Sunlamp-fog-aged panel	
		Average pH	Flexural strength	Flexural strength	Loss due to aging	Flexural strength	Loss due to aging
			lb/in.²	*lb/in.²*	*Percent*	*lb/in.²*	*Percent*
Bakelite XC-11749	None	4.8	27,600	22,200	19.6	21,900	20.6
Do	45% XK-11753	3.1	20,500	16,300	18.0	15,300	25.4
Catabond 590	None	3.5	28,100	21,700	22.8	22,100	21.4
Do	11% hydrochloric acid (27.8%)	1.8	15,600	10,800	30.8	11,000	29.5
Uformite 500	None	6.7	23,000	19,100	17.0	18,600	19.1
Do	10% ammonium chloride	1.5	14,800	7,900	46.6	6,700	54.7

The acidity of the test panels was determined by grinding a portion of the panel to 40 mesh in a Wiley mill and suspending 1 g of the powder in 5 ml of distilled water. The pH values of the water suspensions were usually constant after 48 hours.

The pH of the distilled water used in making the resin suspensions was 6.3. A few of the resin films and powdered panels were also suspended in dilute hydrochloric acid solution of pH 4.5. The pH values of the acid suspensions are reported in table 2 and do not differ appreciably from those of the water suspensions. All the pH measurements were made at a temperature of 77° F (25° C) with a glass electrode. The measurements reported are accurate to ±0.05 pH unit.

3. Strength Properties

The test specimens for determining the strength properties were cut from the quarter sections after the aging treatments. The specimens were machined and then conditioned at 77° F (25° C) and 50-percent relative humidity for at least 48 hours prior to testing. All the tests were made at 77° F (25° C) and 50-percent relative humidity.

The flexural modulus of elasticity was measured on an Olsen Stiffness Tester, Tour-Marshall design. Specimens 5 in. long and 0.5 in. wide were cut from the panels. Two measurements were made on each specimen, one on each end. The test span was 2 in. long; the total bending moment applied to the specimen was 3 in.-lb. The angular deflections were plotted against the bending moments and the deflection at a stress of 2,500 lb/in.² was determined from the curve. A stress of 2,500 lb/in.² was selected because the plots for all the samples were essentially straight lines up to that stress. The secant modulus of elasticity in flexure then was calculated from the approximate expression,

$$E=\frac{229.2PL^2}{Dah^3}, \tag{1}$$

where

E=modulus of elasticity in flexure
P=load
L=length of beam
D=deflection, degrees
a=width of beam, and
h=thickness of beam.

This expression was derived from the formula for the deflection of a cantilever beam with a concentrated load at one end.

The flexural strength was measured on specimens 1.0 in. long and 0.75 in. wide cut from the panels. The specimen was supported on two parallel supports with a span of ⅝ in. The load was applied at the center of the span by a pressure piece similar to the supports. The edges of the support pieces and of the pressure piece were rounded to ⅛-in. radius. The tests were made on a hydraulic testing machine with a head speed of 0.05 in./min. The machine was accurate to 2 percent of the lowest applied load. The flexural strength or modulus of rupture is calculated from the expression

$$F=\frac{3PL}{2ah^2}, \tag{2}$$

where F is flexural strength, and the other symbols have the same significance as in eq. 1.

The impact tests were made on an Izod impact machine of 2 ft-lb capacity. Specimens 2.5 in. long and 0.5 in. wide were cut from the panels.

The tensile tests were made according to Method 1011 of Federal Specification L–P–406. Type 1 specimens were used; the width of the reduced section was 0.5 in. The tests were made on a hydraulic testing machine with self-aligning Templin grips. The rate of head speed was 0.05 in./min.

Shear specimens 4 in. long and 0.75 in. wide were cut from the panels. A groove ⅛ in. wide and extending through approximately 4½ veneers was milled on one face of the panel parallel to the 0.75-in. dimension. A similar groove was milled on the opposite face. The grooves on the specimens used in the preliminary tests were ½ in. apart, but, as many tensile failures were obtained, the distance between the grooves was reduced to ¼ in. on the later specimens. The specimens were broken on a hydraulic testing machine at a rate of loading of 200 lb/in.² per minute.

4. Delamination

One strip 0.5 in. wide cut from each quarter section of each test panel was subjected to a delamination test. The strips were placed in individual 3- by 20-centimeter test tubes that contained distilled water previously heated to the boiling point by immersion of the tubes in a water bath. The tubes containing the test strips were left in

the bath of boiling water for 1 hour. On removal from the test tubes the specimens were immersed in water at 77° F (25° C) for 15 minutes and then dried at 140° F (60° C) in a forced-draft oven for 22 hours. This procedure constituted one cycle of the test. At the end of each cycle the test specimens were bent over a mandrel of 8-in. radius. After five cycles the specimens were bent over a 4-in. radius mandrel. Observations regarding delamination were made.

5. Density

Density was determined by weighing and measuring machined specimens.

V. Results of Tests

A preliminary investigation was made to obtain data for use in selecting the strength properties to be measured on all the test panels. Six panels were prepared with a phenol-formaldehyde resin (Tego film) and six with a urea-formaldehyde resin (Uformite 430 catalyzed with 10-percent ammonium chloride). These two materials were selected to determine the effects of high and low pH conditions respectively. Specimens from each panel were tested unaged and after exposure to three aging tests. The strength properties measured in these preliminary tests were flexural modulus of elasticity, and flexural, impact, tensile, and shear strengths. The changes in these strength properties as a result of exposure to the aging conditions are given in table 3.

On the basis of the results obtained in these preliminary tests, the size of the test specimens required, and an analysis of the stresses in the various tests, it was decided to employ the flexural, impact, and shear strengths for detecting the deterioration of the resin-bonded birch plywoods.

The detailed results of these tests are presented in tables 4, 5, and 6 and figures 5 to 12, inclusive. The behavior of the materials with respect to delamination is shown in table 7. A summary of the effects of the catalysts on the strength properties of the panels bonded with urea-formaldehyde and phenol-formaldehyde resins is given in table 8.

The specific effects of various acid and basic radicals in catalysts used with phenolic resinous adhesives in the preparation of plywood were determined in a series of tests with known compounds. Panels were prepared with a resorcinol-formaldehyde resin (Penacolite G–1131) to which was added varying amounts of hydrochloric, nitric, sulfuric, phosphoric, hypophosphorous, trichloroacetic, benzenesulfonic, and nitranilic acids, and

TABLE 3.—*Changes in strength properties of birch plywoods caused by various aging methods*

Panel designation	Change for panels bonded with phenolic resin (Tego film)			Change for panels bonded with urea-formaldehyde resin (Uformite 430 with 10-percent ammonium chloride catalyst)		
	Oven-aged	Oven-fog-aged	Roof-aged 6 months	Oven-aged	Oven-fog-aged	Roof-aged 6 months
	TENSILE STRENGTH					
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
A	0	+3	+7	−14	−21	+19
B	+7	+6	−11	−22	−4	−42
	FLEXURAL STRENGTH					
A	−6	−1	−7	−15	−41	−53
B	−12	+3	−5	−10	−51	−72
	SECANT FLEXURAL MODULUS OF ELASTICITY (0 TO 2,500 LB/IN.²)					
A	−25	+12	−23	−15	0	−18
B	−18	+17	−13	−25	0	−2
	IZOD IMPACT STRENGTH, FLATWISE					
A	+36	+14	−26	−18	−38	−20
B	0	−28	+38	−10	−27	+10
	IZOD IMPACT STRENGTH, EDGEWISE					
A	+17	−7	+17	−38	−50	+8
B	−11	−18	−18	−15	−6	+80
	SHEAR STRENGTH					
A	+11	−46	−33	−5	−50	−5
B	−43	+70	−25	+5	−38	--------

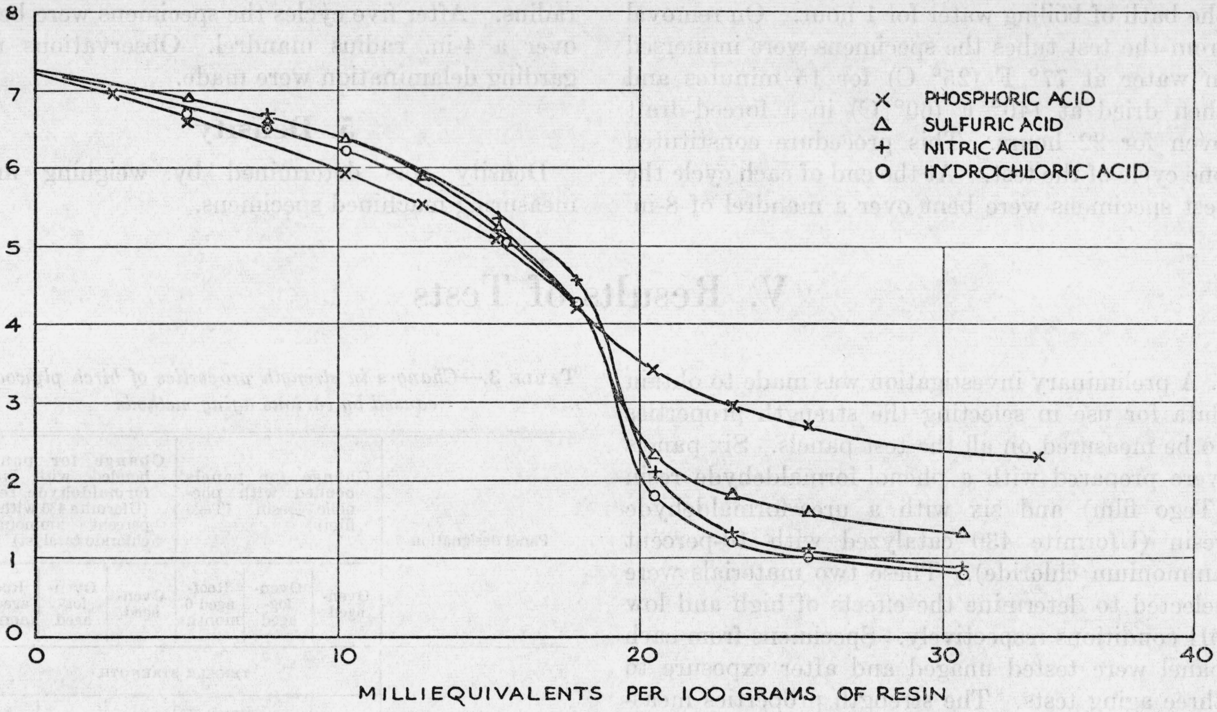

FIGURE 1.—*Titration of Penacolite G-1131 with various acids.*

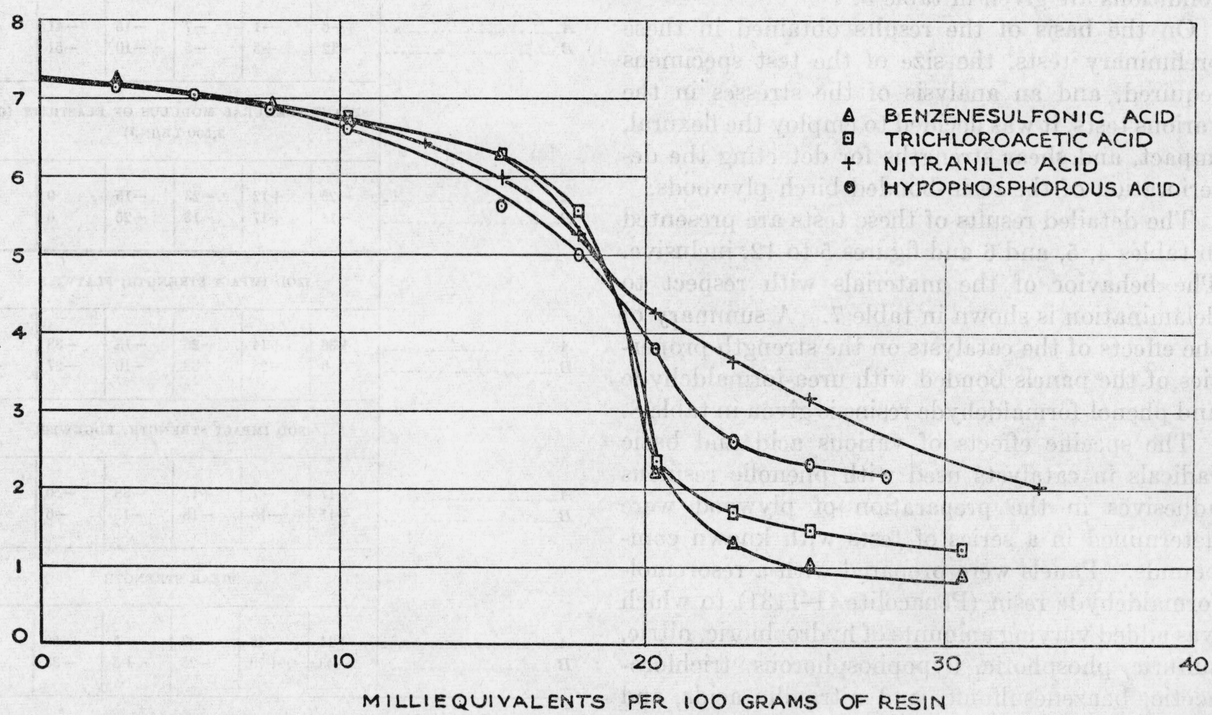

FIGURE 2.—*Titration of Penacolite G-1131 with various acids.*

sodium hydroxide. Titration curves of the resin with these acids and base are shown in figures 1, 2, and 3. The flexural strengths of these panels, unaged and oven-fog-aged, are presented in table 9.

Similar experiments were performed with two phenol-formaldehyde resins. The titration curves obtained for one of these resins (Cascophen LT–67) with the acids and base are shown in figures 3 and 4. The results of the strength tests are given in table 10.

In a further series of tests to determine the specific effect of the acid radicals in commercial catalysts for resinous adhesives, three commercial catalysts were used, respectively, with three phenolic resins to prepare plywood panels. Four panels were prepared with each resin—one without catalyst, and one with each of the three catalysts, respectively. Only one of the resin-catalyst mixtures failed to cure satisfactorily at 150°F (66°C). The flexural strengths of these panels were determined before and after aging. The results of these tests are presented in table 11. Data are also given in table 11 for one of the resin-catalyst mixtures in which the catalyst percentage was varied from 5 to 45 percent.

Proper interpretation of the data obtained in these experiments on the effects of various acid and alkaline catalysts on the strength of resin-bonded plywood required information on the effects of these chemicals on the wood itself. Accordingly, birch veneers of 0.1-in. thickness were immersed for 3 days in various concentrations of the same acids and alkalies used in the tests with the resins. The results of flexural strength measurements on the conditioned wood specimens are shown in table 12.

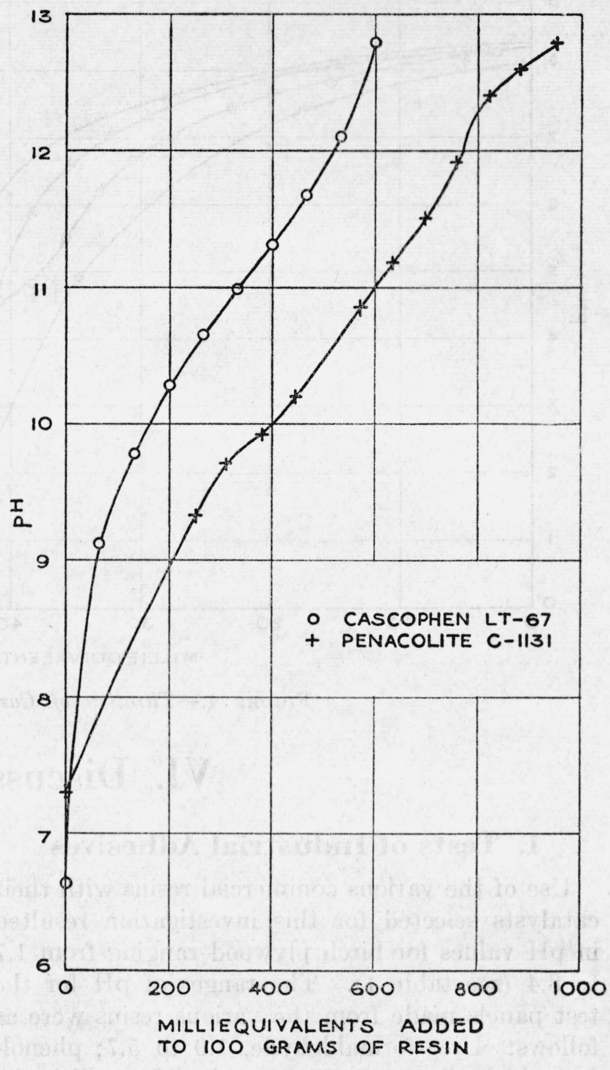

FIGURE 3.—*Titration of phenol and resorcinol resins with sodium hydroxide.*

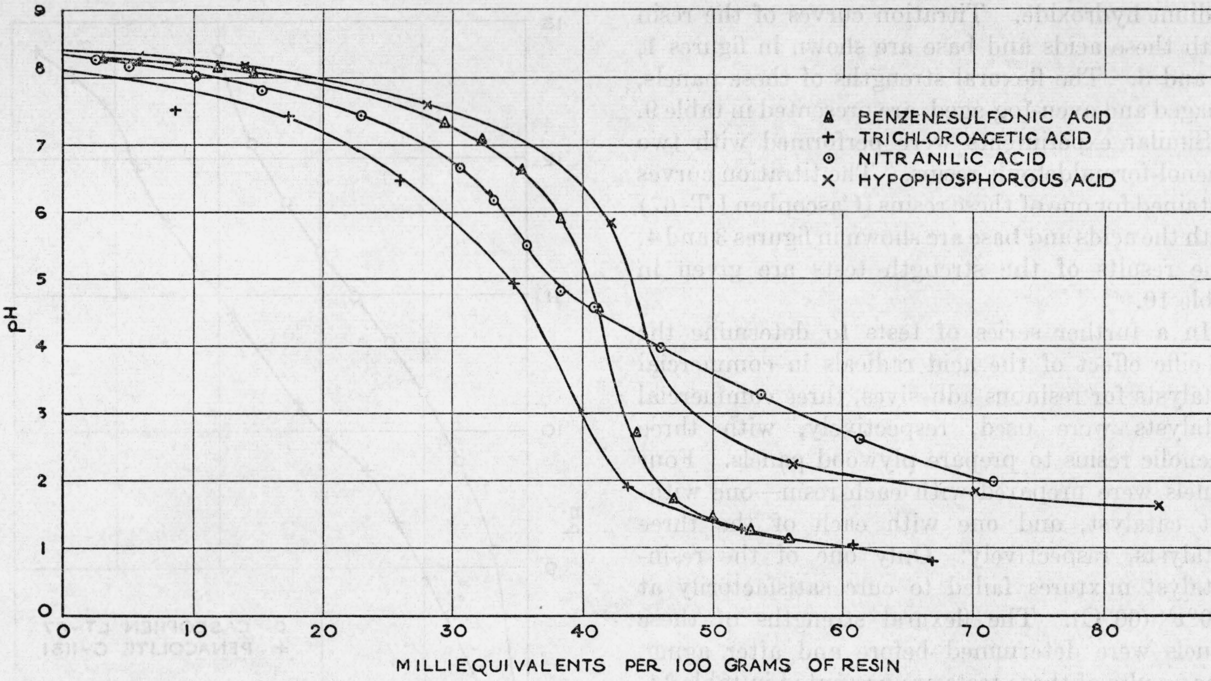

FIGURE 4.—*Titration of Cascophen LT–67 with various acids.*

VI. Discussion of Results

1. Tests of Industrial Adhesives

Use of the various commercial resins with their catalysts selected for this investigation resulted in pH values for birch plywood ranging from 1.7 to 8.4 (see table 1). The ranges of pH for the test panels made from the various resins were as follows: Urea-formaldehyde, 1.9 to 5.7; phenol-formaldehyde, 1.7 to 8.4; resorcinol-formaldehyde, 4.8 to 6.3; and unsaturated polyester resins, 3.2 to 5.7.

The pH values of birch plywood were not affected by moderate baking or by exposure to cycles of heat and fog. This indicated that the acidic compounds determining the pH of the composite did not escape readily from the structure or did not react with the birch or its decomposition products in such a way that they lost their chemical identity. It would seem reasonable, therefore, to assume that the deterioration caused by pH would continue until failure occurred.

The results of the 240-hour oven-fog-aging test are in qualitative agreement with the results of the 1-year roof-aging test. An analysis of the data indicates that no quantitative statements can be made concerning the agreement. However, the 1-year roof-aging test was usually, but not always, more severe than the 240-hour oven-fog-aging test.

The effects of pH on the strength of the plywood prepared with the various commercial types of resins can best be reviewed by discussing the resins in the following three groups: Urea, phenolic, and other resins.

(a) Urea Resins

The flexural, impact, and shear strengths of the urea-formaldehyde resin-bonded birch plywood depended markedly on the pH of the composite. This is shown by the data in tables 4, 5, and 6 and graphically in figures 5, 6, and 7.

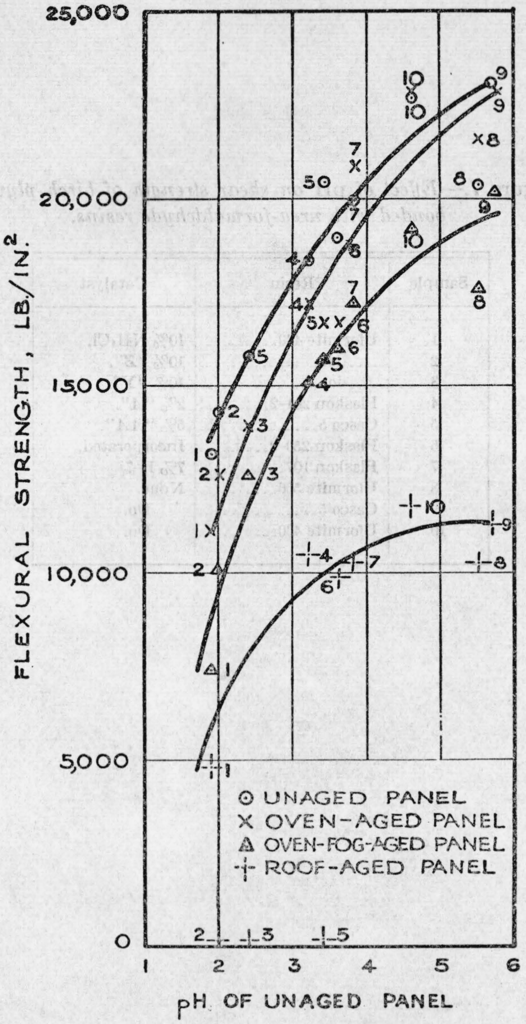

FIGURE 5.—*Effect of* pH *on flexural strength of birch plywood bonded with urea-formaldehyde resins.*

Sample	Resin	Catalyst
1	Uformite 430	10%NH$_4$Cl.
2	do	10% "*Z*".
3	do	10% "*Y*".
4	Plaskon 201-2	2% "*A*".
5	Casco 5	5% "*AA*".
6	Plaskon 250-2	Incorporated.
7	Plaskon 107	7% B-7.
8	Uformite 500	None.
9	Casco 5	Do.
10	Uformite 430	Do.

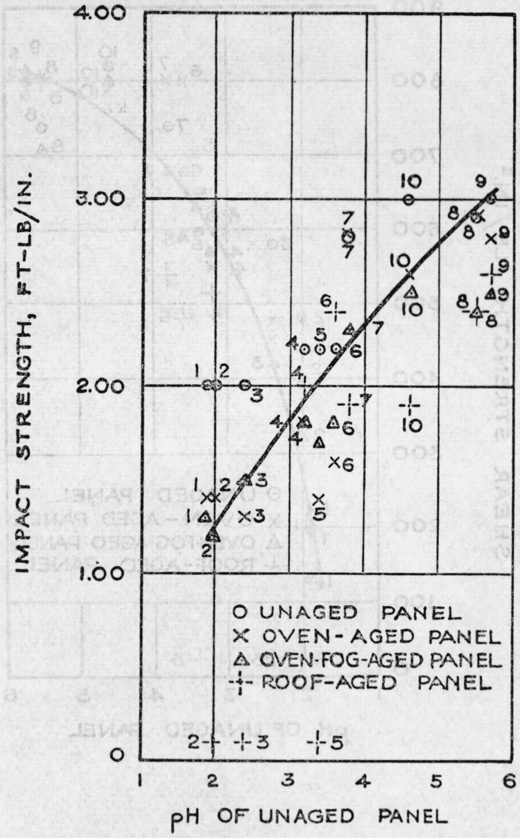

FIGURE 6.—*Effect of* pH *on impact strength of birch plywood bonded with urea-formaldehyde resins.*

Sample	Resin	Catalyst
1	Uformite 430	10% NH$_4$Cl.
2	do	10% "*Z*"
3	do	10% "*Y*".
4	Plaskon 201-2	2% "*A*".
5	Casco 5	5% "*A*".
6	Plaskon 250-2	Incorporated.
7	Plaskon 107	7% B-7.
8	Uformite 500	None.
9	Casco 5	Do.
10	Uformite 430	Do.

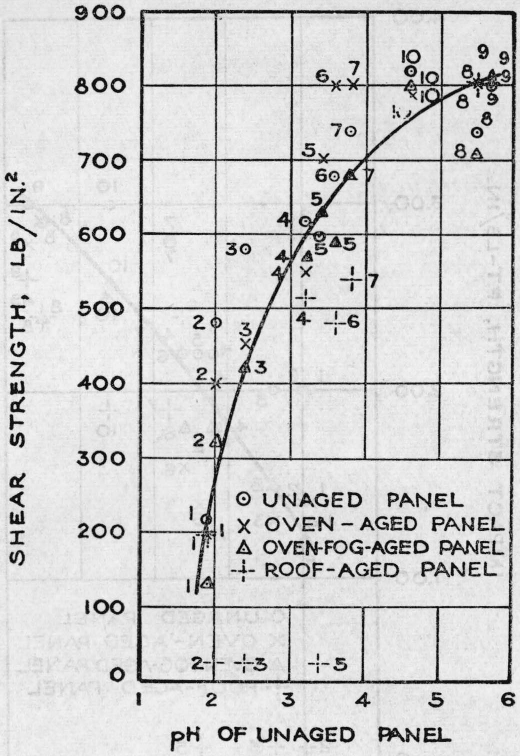

Figure 7.—*Effect of* pH *on shear strength of birch plywood bonded with urea-formaldehyde resins.*

Sample	Resin	Catalyst
1	Uformite 430	10% NH_4Cl.
2	do	10% "Z".
3	do	10% "Y".
4	Plaskon 201-2	2% "A".
5	Casco 5	5% "AA".
6	Plaskon 250-2	Incorporated.
7	Plaskon 107	7% B-7.
8	Uformite 500	None.
9	Casco 5	Do.
10	Uformite 430	Do.

TABLE 4.—*Effect of catalyst and pH on flexural strength of resin-bonded birch plywood*

Commercial designation of resin	Catalyst added to resin	Classification	pH of unaged panel	Flexural strength data: Unaged panel: Flexural strength: Average	Unaged panel: Flexural strength: Range	Unaged panel: No. of specimens	Oven-aged panel: Flexural strength: Average	Oven-aged panel: Flexural strength: Range	Oven-aged panel: No. of specimens	Oven-aged panel: Change in strength	Oven-fog-aged panel: Flexural strength: Average	Oven-fog-aged panel: Flexural strength: Range	Oven-fog-aged panel: No. of specimens	Oven-fog-aged panel: Change in strength	Roof-aged panel: Flexural strength: Average	Roof-aged panel: Flexural strength: Range	Roof-aged panel: No. of specimens	Roof-aged panel: Change in strength
UREA-FORMALDEHYDE RESINS																		
				lb/in.²	*lb/in.²*		*lb/in.²*	*lb/in.²*		*Percent*	*lb/in.²*	*lb/in.²*		*Percent*	*lb/in.²*	*lb/in.²*		*Percent*
Uformite 430	10% NH_4Cl	*R*	1.9	13,200	10,800 to 15,500	12	11,100	9,900 to 12,800	8	−16	7,400	5,600 to 9,400	16	−44	4,800[c]	2,800 to 6,200	6	−64
Do	10% "Z"	*R*	2.0	14,300	11,300 to 15,600	12	12,600	11,100 to 15,000	12	−12	10,100	7,800 to 12,200	12	−29	([a])			
Do	10% "Y"	*R*	2.4	15,800	14,600 to 17,400	12	13,900	11,500 to 15,600	11	−12	12,600	9,600 to 14,200	11	−20	([a])			
Plaskon 201-2	2% "A"	*R*	3.2	18,400	16,900 to 19,800	12	17,200	15,800 to 18,900	12	−7	15,100	12,300 to 17,700	12	−18	10,500	8,500 to 11,600	12	−43
Casco 5	5% "AA"	*R*	3.4	20,500	18,800 to 22,300	12	16,700	13,400 to 19,700	11	−19	15,700	12,200 to 20,700	12	−23	([a])			
Plaskon 250-2	Incorporated with resin.	*R*	3.6	19,000	17,100 to 19,600	12	16,700	12,800 to 19,600	12	−12	16,000	15,200 to 17,700	12	−16	9,900	8,400 to 11,400	12	−48
Plaskon 107	7% B-7	*H*	3.8	20,000	16,500 to 21,200	15	20,400	18,200 to 21,200	12	+2	17,200	16,000 to 20,400	12	−14	10,300	9,200 to 11,500	15	−49
Uformite 500	None	*H*	5.5	20,400	16,600 to 24,000	15	21,600	18,200 to 23,600	15	+6	17,600	11,800 to 19,100	11	−14	10,300	9,700 to 11,300	15	−50
Casco 5	do	*H*	5.7	23,100	19,300 to 26,600	13	23,000	19,600 to 25,600	15	−0.4	21,200	16,600 to 26,700	13	−8	11,300	8,000 to 13,700	15	−51
Uformite 430	do	*H*	4.6	22,700	20,700 to 25,700	15	22,800	19,500 to 27,400	15	+0.4	19,200	17,000 to 24,100	15	−15	11,800	5,800 to 13,900	15	−48
UREA-RESORCINOL-FORMALDEHYDE RESINS																		
Uformite 500	20% Q-107; 0.7% Q-87.	*M*	5.1	19,100	16,400 to 22,500	12	21,400	17,800 to 25,400	12	+12	20,800	18,500 to 23,700	12	+9	11,000	9,000 to 12,400	12	−43
Plaskon 700-2	16% modifier	*M*	4.6	21,800	20,500 to 23,400	12	22,900	20,300 to 25,700	12	+5	21,300	15,900 to 24,800	12	−2	16,000	14,000 to 18,000	12	−27
PHENOL-FORMALDEHYDE RESINS																		
Durez 12041	10% 7422	*M*	1.8	19,400	17,300 to 20,600	12	19,000	17,100 to 21,800	11	−2	13,500	10,100 to 15,300	12	−30	9,600	8,400 to 10,900	12	−51
Durez 11427	10% 7422	*M*	1.8	20,200	16,700 to 21,800	12	18,200	15,100 to 20,500	12	−10	11,800	9,900 to 13,900	12	−42	10,400	8,800 to 12,200	12	−49
Catabond 590	11% HCl acid (27.8%).	*M*	1.7	10,500	6,800 to 12,700	12	11,100	8,700 to 12,500	12	+5	9,300	7,800 to 11,600	12	−11	6,100	5,300 to 7,000	12	−42
Catabond 200CZ	11% HCl acid (27.8%).	*M*	1.8	11,700	8,800 to 17,400	12	13,100	10,800 to 16,900	12	+12	9,800	7,000 to 12,600	12	−16	6,600	5,700 to 9,500	12	−44
Bakelite XC-3931	3% XK-2997	*M*	2.7	17,300	15,200 to 19,900	12	16,200	10,600 to 20,000	12	−6	11,600	8,800 to 13,600	12	−33	9,800	4,900 to 11,500	12	−43
Bakelite XC-11749.	45% XK-11753	*R*	3.1	18,400	15,400 to 19,700	12	17,700	12,500 to 23,100	12	−4	12,900	8,700 to 15,300	12	−30	9,800	6,000 to 11,400	12	−47
Catabond 590	None	*H*	3.6	24,000	21,300 to 25,800	15	26,700	23,400 to 29,700	15	+11	21,700	18,100 to 25,200	15	−10	17,000	14,800 to 19,000	10	−29
Bakelite XC-3931	do	*H*	4.5	23,600	18,100 to 30,000	15	25,100	22,900 to 28,900	15	+7	24,800	23,300 to 26,300	15	+5	10,700	9,100 to 12,800	15	−55
Bakelite XC-11749.	do	*H*	3.9	24,600	22,100 to 26,800	15	27,900	23,300 to 29,700	15	+13	21,900	18,300 to 24,100	15	−11	14,200	11,500 to 16,000	15	−43
Catabond 200CZ	do	*H*	4.6	24,000	21,300 to 25,800	15	26,500	23,000 to 29,200	15	+10	25,000	19,900 to 27,300	15	+4	17,400	15,300 to 18,600	10	−28
Cascophen LT-67	8% M-18	*M*	6.4	21,900	17,600 to 24,200	12	25,400	23,200 to 27,100	12	+16	21,900	19,100 to 24,100	12	0	13,900	10,400 to 16,200	12	−37
Durez 12041	None	*H*	5.0	24,700	22,400 to 28,700	15	26,500	21,700 to 30,700	15	+8	23,800	21,300 to 27,100	15	−4	17,800	15,300 to 21,000	15	−28
Bakelite BC-17540.	15% BC-17545	*M*	7.3	20,200	17,900 to 21,600	30					20,000	18,600 to 21,400	30	−1	12,800	10,800 to 14,200	30	−37
Tego film	None	*H*	8.2	19,700	14,400 to 21,000	10	17,900	16,000 to 19,200	4	−9	17,500	13,900 to 21,700	8	−11	19,000[c]	14,300 to 20,700	12	−4
Amberlite PR-14	Incorporated with resin.	*H*	8.4	21,800	16,000 to 25,300	15	22,600	20,100 to 25,600	15	+4	20,500	18,600 to 24,400	15	−6	13,400	8,300 to 16,400	15	−38

See footnotes at end of table.

TABLE 4.—*Effect of catalyst and* pH *on flexural strength of resin-bonded birch plywood*—Continued

Commercial designation of resin	Catalyst added to resin	Classification	pH of unaged panel	Unaged panel: Flexural strength: Average	Unaged panel: Flexural strength: Range	Unaged panel: No. of specimens	Oven-aged panel: Flexural strength: Average	Oven-aged panel: Flexural strength: Range	Oven-aged panel: No. of specimens	Oven-aged panel: Change in strength	Oven-fog-aged panel: Flexural strength: Average	Oven-fog-aged panel: Flexural strength: Range	Oven-fog-aged panel: No. of specimens	Oven-fog-aged panel: Change in strength	Roof-aged panel: Flexural strength: Average	Roof-aged panel: Flexural strength: Range	Roof-aged panel: No. of specimens	Roof-aged panel: Change in strength
RESORCINOL-FORMALDEHYDE RESINS																		
				lb/in.²	*lb/in.²*		*lb/in.²*	*lb/in.²*		*Percent*	*lb/in.²*	*lb/in.²*		*Percent*	*lb/in.²*	*lb/in.²*		*Percent*
Durez 12490	11% formaldehyde.	*R*	4.8	17,500	15,400 to 19,100	12	19,600	17,600 to 21,000	12	+12	17,500	16,500 to 18,900	12	0	10,700	9,200 to 12,200	12	−39
Penacolite G-1131	20% G-1131B	*R*	5.1	19,200	17,100 to 21,800	36	-----	-----	-----	-----	21,600	19,200 to 25,100	36	+13	12,000	9,600 to 14,900	36	−38
Bakelite XC-17613.	20% XK-17618	*M*	4.8	21,200	18,200 to 22,400	30	-----	-----	-----	-----	19,800	16,300 to 21,900	30	−7	12,800	10,700 to 14,300	28	−40
Amberlite PR-75B.	22% P-79	*M*	5.4	20,200	17,600 to 22,400	36	-----	-----	-----	-----	19,600	16,200 to 21,600	35	−3	11,000	9,200 to 12,700	32	−46
Penacolite G-1124	25% G-1124B	*R*	5.1	21,600	19,700 to 23,400	12	23,100	21,400 to 24,400	12	+7	18,000	16,100 to 19,400	11	−17	10,100	8,200 to 11,800	12	−53
Durite S-3026	16% 3026A	*R*	6.3	17,600	14,700 to 20,000	30	-----	-----	-----	-----	17,500	16,200 to 19,200	30	−0.6	10,700	9,800 to 11,900	30	−39
PHENOL-RESORCINOL-FORMALDEHYDE RESIN																		
Durez 12533	100% 12534B	*M*	5.1	22,300	21,100 to 23,800	12	23,400	21,400 to 26,000	12	+5	21,300	20,000 to 23,000	12	−5	10,700	9,400 to 12,800	12	−52
FURANE RESIN																		
Resin X	5% Z-1A	*R*	2.2	17,100	14,800 to 20,000	36	-----	-----	-----	-----	16,400	12,700 to 20,800	36	−5	8,500	7,000 to 10,800	36	−50
CASEIN GLUE																		
Aircraft joint P glue.	None	*R*	8.4	18,100	14,400 to 20,100	12	20,700	12,300 to 23,600	12	+14	17,200	12,700 to 18,600	12	−5	(a)	-----	-----	-----
UNSATURATED POLYESTER RESINS																		
Laminac	1% benzoyl peroxide.	*H*	3.7	15,300	12,700 to 18,500	13	19,800	12,400 to 23,300	15	+29	17,800	16,900 to 19,600	12	+16	9,900	9,400 to 10,800	10	−35
Do	1% lauroyl peroxide.	*H*	4.0	18,800	17,000 to 21,000	15	19,500	15,000 to 20,700	15	+4	16,300	12,200 to 19,800	15	−13	9,500	9,000 to 10,600	15	−49
MR-17-A2	3% benzoyl peroxide.	*H*	3.7	24,300	22,500 to 26,700	15	23,200	20,800 to 25,800	15	−5	20,900	17,900 to 23,700	14	−14	10,100	8,600 to 11,800	15	−59
BR-17-B1	do	*H*	3.2	22,900	20,500 to 26,100	15	22,400	19,700 to 27,000	15	−2	20,300	18,700 to 23,200	15	−11	9,700	8,900 to 11,300	15	−58
Plaskon 900	2% benzoyl peroxide.	*M*	3.8	15,500	9,300 to 19,600	30	-----	-----	-----	-----	15,500	11,200 to 18,800	30	0	7,200	6,100 to 10,000	17[b]	−54
CR-39	5% benzoyl peroxide.	*H*	3.9	24,600	21,500 to 27,100	20	23,600	20,900 to 26,700	15	−4	24,700	21,200 to 27,700	15	+0.4	12,300	10,500 to 14,000	15	−50

[a] Panels delaminated during exposure on roof.

[b] The 3 panels exposed delaminated partially so that only 17 specimens were obtained instead of 30 as planned.

[c] Panels exposed on roof for only 6 months.

TABLE 5.—*Effect of catalyst and pH on the impact strength of resin-bonded birch plywood*

Commercial designation of resin	Catalyst added to resin	Classification	pH of unaged panel	Impact strength (edgewise)														
				Unaged panel			Oven-aged panel				Oven-fog-aged panel				Roof-aged panel			
				Impact strength		No. of specimens	Impact strength		No. of specimens	Change in strength	Impact strength		No. of specimens	Change in strength	Impact strength		No. of specimens	Change in strength
				Average	Range		Average	Range			Average	Range			Average	Range		
UREA-FORMALDEHYDE RESINS																		
				ft-lb	*ft-lb*		*ft-lb*	*ft-lb*		*Percent*	*ft-lb*	*ft-lb*		*Percent*	*ft-lb*	*ft-lb*		*Percent*
Uformite 430	10% ammonium chloride.	*R*	1.9	2.0	1.4 to 2.5	12	1.4	1.2 to 1.6	8	−30	1.3	0.8 to 1.8	8	−35	[b]3.0	3.0 to 3.1	5	+50
Do	10% "Z"	*R*	2.0	2.0	1.5 to 2.8	6	1.4	0.8 to 1.6	6	−30	1.2	.9 to 1.6	6	−40	([a])			
Do	10% "Y"	*R*	2.4	2.0	1.9 to 2.0	6	1.3	1.1 to 1.5	6	−35	1.5	1.4 to 1.8	6	−25	([a])			
Plaskon 201-2	2% "A"	*R*	3.2	2.2	1.8 to 2.5	6	1.8	1.6 to 2.2	6	−18	1.8	1.1 to 3.0	6	−18	2.0	1.8 to 2.4	6	−9
Casco 5	5% "AA"	*R*	3.4	2.2	2.0 to 2.4	6	1.4	1.1 to 1.6	6	−36	1.7	1.5 to 1.9	6	−23	([a])			
Plaskon 250-2	Incorporated with resin.	*R*	3.6	2.2	1.8 to 2.8	6	1.6	1.4 to 1.8	6	−27	1.8	1.8 to 2.1	6	−18	2.4	1.7 to 2.8	6	+9
Plaskon 107	7% B-7	*H*	3.8	2.8	2.6 to 3.1	18	2.8	2.7 to 2.9	18	0	2.3	2.2 to 2.3	18	−18	1.9	1.8 to 1.9	18	−32
Uformite 500	None	*H*	5.5	2.9	2.1 to 3.6	18	2.9	2.2 to 4.5	18	0	2.4	2.3 to 2.4	18	−17	2.4	2.3 to 2.4	18	−17
Casco 5	do	*H*	5.7	3.0	3.0 to 3.2	15	2.8	2.7 to 3.0	13	−7	2.5	2.0 to 2.9	14	−17	2.6	1.8 to 3.1	14	−13
Uformite 430	do	*H*	4.6	3.0	2.8 to 3.3	18	2.6	2.5 to 2.9	18	−13	2.5	2.2 to 2.7	18	−17	1.9	1.8 to 2.0	18	−37
UREA-RESORCINOL-FORMALDEHYDE RESINS																		
Uformite 500	20% Q-107; 0.7% Q-87	*M*	5.1	2.7	2.2 to 3.2	6	2.8	2.4 to 3.0	6	+4	1.9	1.6 to 2.2	3	−30	1.9	1.6 to 2.2	3	−30
Plaskon 700-2	16% Modifier	*M*	4.0	4.6	3.6 to 4.2	6	3.2	2.9 to 3.8	6	−20	2.5	2.1 to 2.7	6	−38	2.1	2.0 to 2.1	6	−48
PHENOL-FORMALDEHYDE RESINS																		
Durez 12041	10% 7422	*M*	1.8	2.3	2.0 to 2.5	6	2.1	1.6 ro 2.7	6	−9	1.6	1.2 to 1.8	5	−30	1.0	1.0 to 1.1	6	−57
Durez 11427	10% 7422	*M*	1.8	3.0	2.5 to 3.5	6	2.0	1.8 to 2.1	6	−33	1.3	0.9 to 2.0	6	−57	1.2	1.1 to 1.4	6	−60
Catabond 590	11% HCl acid (27.8%)	*M*	1.7	1.3	1.2 to 1.5	6	0.7	0.5 to 0.8	6	−46	0.8	.7 to 0.9	6	−39	0.7	0.6 to 0.7	6	−46
Catabond 200-CZ	11% HCl acid (27.8%)	*M*	1.8	1.4	1.3 to 1.6	6	1.2	.9 to 1.5	6	−14	1.1	.9 to 1.2	6	−21	.7	.6 to 0.7	5	−50
Bakelite XC-3931	3% XK-2997	*M*	2.7	2.2	2.0 to 2.4	6	1.4	1.3 to 1.6	6	−36	1.5	1.4 to 1.5	6	−32	1.1	1.0 to 1.2	6	−50
Bakelite XC-11749	45% XK-11753	*R*	3.1	2.0	1.9 to 2.3	6	2.0	1.6 to 2.7	6	0	1.3	1.2 to 1.5	6	−35	1.2	0.8 to 1.9	6	−40
Catabond 590	None	*H*	3.6	3.4	3.2 to 3.6	17	3.4	3.3 to 3.5	18	0	2.9	2.8 to 3.1	18	−15	1.9	1.9 to 2.0	12	−44
Bakelite XC-3931	do	*H*	4.5	3.2	3.1 to 3.3	18	3.4	2.5 to 3.6	18	+6	2.8	2.7 to 3.0	18	−13	1.6	1.3 to 3.0	18	−50
Bakelite XC-11749	do	*H*	3.9	2.6	2.4 to 2.9	18	3.1	2.9 to 3.2	18	+19	2.5	2.1 to 2.9	18	−4	1.6	1.4 to 1.8	18	−38
Catabond 200-CZ	do	*H*	4.6	3.5	3.2 to 3.6	18	3.8	3.7 to 3.9	18	+9	3.0	3.0 to 3.1	18	−14	1.6	1.6 to 1.6	12	−54
Cascophen LT-67	8% M-18	*M*	6.4	2.7	2.4 to 3.0	6	2.6	1.9 to 3.9	6	−4	2.3	2.0 to 2.3	6	−15	2.1	1.5 to 2.8	6	−22
Durez 12041	None	*H*	5.0	3.3	3.1 to 3.4	18	3.4	3.3 to 3.5	18	−3	2.7	2.3 to 3.4	18	−18	2.0	1.9 to 2.2	16	−39
Tego film	Incorporated with resin.	*H*	8.2	3.0	2.4 to 3.7	23	2.8	2.6 to 3.0	8	−7	2.9	2.8 to 2.9	8	−3.3	[b]2.9	2.5 to 3.2	8	−3.3
Amberlite PR-14	do	*H*	8.4	3.0	2.7 to 3.4	18	3.6	2.9 to 3.7	18	+20	3.0	2.9 to 3.2	18	0	2.2	2.2 to 2.2	18	−27

Footnotes at end of table, p. 296.

TABLE 5.—*Effect of catalyst and pH on the impact strength of resin-bonded birch plywood*—Continued

Commercial designation of resin	Catalyst added to resin	Classification	pH of unaged panel	Impact strength (edgewise)														
				Unaged panel			Oven-aged panel				Oven-fog-aged panel				Roof-aged panel			
				Impact strength		No. of specimens	Impact strength		No. of specimens	Change in strength	Impact strength		No. of specimens	Change in strength	Impact strength		No. of specimens	Change in strength
				Average	Range		Average	Range			Average	Range			Average	Range		
				RESORCINOL-FORMALDEHYDE RESINS														
				ft-lb	*ft-lb*		*ft-lb*	*ft-lb*		*Percent*	*ft-lb*	*ft-lb*		*Percent*	*ft-lb*	*ft-lb*		*Percent*
Durez 12490	30% formaldehyde (37%).	*R*	4.8	3.3	3.0 to 3.4	6	3.1	2.5 to 3.5	6	−6	2.9	2.7 to 3.0	3	−12	2.9	2.7 to 3.0	3	−12
Penacolite G-1124	25% g-1124B	*R*	5.1	3.1	2.9 to 3.4	6	2.8	2.5 to 3.1	6	−10	3.3	2.3 to 4.5	6	+6	1.7	1.3 to 2.6	6	−45
				PHENOL-RESORCINOL-FORMALDEHYDE RESIN														
Durez 12533	100% 12534B	*M*	5.1	3.5	3.4 to 3.6	6	2.3	1.9 to 2.8	6	−34	2.3	2.0 to 2.8	6	−34	2.3	2.1 to 2.8	6	−34
				CASEIN GLUE														
Aircraft joint P glue	None	*R*	8.4	5.0	4.2 to 6.1	6	3.9	3.6 to 4.1	6	−22	3.2	2.3 to 4.0	5	−36	(a)			
				UNSATURATED POLYESTER RESINS														
Laminac	1% benzoyl peroxide	*H*	3.7	3.9	3.7 to 4.2	18	4.0	3.8 to 4.1	18	+3	3.6	3.3 to 4.0	18	−8	1.9	1.9 to 2.0	12	−51
Do	1% lauroyl peroxide	*H*	4.0	4.7	4.4 to 5.1	18	4.8	3.5 to 5.8	18	−2	4.2	3.6 to 4.7	18	−11	2.1	1.6 to 2.7	18	−55
MR-17-A2	3% benzoyl peroxide	*H*	3.7	3.5	3.0 to 4.0	18	3.3	1.5 to 4.4	18	−6	3.2	3.1 to 3.3	18	−9	1.9	1.6 to 2.1	18	−46
MR-17-B1	do	*H*	3.2	4.6	4.3 to 4.8	18	4.0	3.4 to 4.6	18	−13	4.2	3.6 to 5.0	18	−9	2.4	2.4 to 2.5	18	−48
CR-39	5% benzoyl peroxide	*H*	3.9	3.8	3.3 to 4.1	18	4.2	3.5 to 4.6	24	+11	4.0	3.5 to 4.4	18	+5	2.9	2.5 to 3.7	18	−24

[a] Panels delaminated during exposure on roof.
[b] Panels exposed for only 6 months.

TABLE 6.—*Effect of catalyst and* pH *on the shear strength of resin-bonded birch plywood*

Commercial designation of resin	Catalyst added to resin	Classification	pH of unaged panel	Shear strength data [a]														
				Unaged panel			Oven-aged panel				Oven-fog-aged panel				Roof-aged panel			
				Shear strength		No. of specimens	Shear strength		No. of specimens	Change in strength	Shear strength		No. of specimens	Change in strength	Shear strength		No. of specimens	Change in strength
				Average	Range		Average	Range			Average	Range			Average	Range		
UREA-FORMALDEHYDE RESINS																		
				lb/in.²	*lb/in.²*		*lb/in.²*	*lb/in.²*		*Percent*	*lb/in.²*	*lb/in.²*		*Percent*	*lb/in.²*	*lb/in.²*		*Percent*
Uformite 430	10% ammonium chloride.	*R*	1.9	220	180 to 260	5	200	180 to 220	4	−9	130	120 to 130	3	−41	200	180 to 220	[c] 2	−9
Do	10% "Z"	*R*	2.0	480	430 to 500	4	400	390 to 420	3	−17	320	280 to 360	6	−33	([b])			
Do	10% "Y"	*R*	2.4	580	520 to 640	5	450	438 to 470	2	−22	420	380 to 510	5	−28	([b])			
Plaskon 201-2	2% "A"	*R*	3.2	620	560 to 670	3	550		1	−11	570	450 to 640	3	−8	540	500 to 640	6	−13
Casco 5	5% "AA"	*R*	3.4	600	530 to 670	4	700		1	+17	630	560 to 680	3	+5	([b])			
Plaskon 250-2	Incorporated with resin.	*R*	3.6	680		1	([d])				590		1	−13	480	430 to 520	4	−29
Plaskon 107	7% B-7	*H*	3.8	740	680 to 800	2	([d])				680		1	−8	540	450 to 640	6	−27
Uformite 500	None	*H*	5.5	740	680 to 810	2	([d])				710	690 to 720	2	−4	([d])			
Casco 5	do	*H*	5.7	([d])			([d])				([d])				([d])			
Uformite 430	do	*H*	4.6	820	720 to 880	4	790		1		([d])			−4	([d])			
UREA-RESORCINOL-FORMALDEHYDE RESINS																		
Uformite 500	20% Q-107; 0.7% Q-87	*M*	5.1	730	680 to 810	3	([d])				650		1	−11	620	600 to 630	2	−15
Plaskon 700-2	16% modifier	*M*	4.6	810	780 to 830	3	750		1	−7	([d])				([d])			
PHENOL-FORMALDEHYDE RESINS																		
Durez 12041	10% 7422	*M*	1.8	([d])			([d])				([d])				([d])			
Durez 11427	10% 7422	*M*	1.8	([d])			([d])				([d])				([d])			
Catabond 590	11% HCl acid (27.8%)	*M*	1.7	([d])			([d])				([d])				([d])			
Catabond 200-CZ	11% HCl acid (27.8%)	*M*	1.8	([d])			([d])				([d])				([d])			
Bakelite XC-3931	3% XK-2997	*M*	2.7	640		1	580	570 to 590	2	−9	([d])				([d])			
Bakelite XC-11749	45% XK-11753	*R*	3.1	390	370 to 410	2	570		1	+46	330		1	−15	([d])			
Catabond 590	None	*H*	3.6	780	760 to 810	3	([d])				790		1	+1	([d])			
Bakelite XC-3931	do	*H*	4.5	([d])			710	690 to 740	3		710	690 to 740	3		([d])			
Bakelite XC-11749	do	*H*	3.9	750	700 to 820	4	700	590 to 760	4	−7	740	670 to 780	3	−1	([d])			
Catabond 200 CZ	do	*H*	4.6	770	720 to 810	2	([d])				([d])				([d])			
Cascophen LT-67	8% M-18	*M*	6.4	640	580 to 690	6	670	650 to 710	3	+5	780	770 to 800	2	+22	([d])			
Durez 12041	None	*H*	5.0	750	680 to 830	4	840	790 to 890	2	+12	760	720 to 800	2	+1	([d])			
Tego Film	Incorporated with resin.	*H*	8.2	600	390 to 1,200	8	450	420 to 520	4	−25	780	620 to 1,030	4	+30	470	400 to 520	[c] 4	−22
Amberlite PR-14	do	*H*	8.4	770	660 to 930	5	([d])				730	440 to 1,020	5	−5	600	380 to 750	3	−22

Footnotes at end of table, p. 298.

TABLE 6.—*Effect of catalyst and* pH *on the shear strength of resin-bonded birch plywood*—Continued

Commercial designation of resin	Catalyst added to resin	Classification	pH of unaged panel	Shear strength data [a]														
				Unaged panel			Oven-aged panel				Oven-fog-aged panel				Roof-aged panel			
				Shear strength		No. of specimens	Shear strength		No. of specimens	Change in strength	Shear strength		No. of specimens	Change in strength	Shear strength		No. of specimens	Change in strength
				Average	Range		Average	Range			Average	Range			Average	Range		
RESORCINOL-FORMALDEHYDE RESINS																		
				lb/in.²	*lb/in.²*		*lb/in.²*	*lb/in.²*		*Percent*	*lb/in.²*	*lb/in.²*		*Percent*	*lb/in.²*	*lb/in.²*		*Percent*
Durez 12490	30% formaldehyde (37%).	*R*	4.8	780	610 to 900	6	740	720 to 800	4	−5	610	530 to 680	5	−22	670	600 to 700	3	−14
Penacolite G-1124	25% G-1124B	*R*	5.1	870	860 to 870	3	820	740 to 900	2	−6	900		1	+3	(d)			
PHENOL-RESORCINOL-FORMALDEHYDE RESIN																		
Durez 12533	100% 12534B	*M*	5.1	750	710 to 810	6	780		1	+4	700	670 to 700	3	−7	(d)			
CASEIN GLUE																		
Aircraft joint P glue	None	*R*	8.4	850	690 to 1,040	6	860		1	+1	560	420 to 640	6	−34	(b)			
UNSATURATED POLYESTER RESINS																		
Laminac	1% benzoyl peroxide	*H*	3.7	520	280 to 640	6	540	490 to 600	6	+4	460	390 to 520	6	−12	500	470 to 540	4	−4
Do	1% lauroyl peroxide	*H*	4.0	500	470 to 550	6	450	380 to 500	6	−10	440	320 to 490	6	−12	420	390 to 440	6	−16
MR-17-A2	3% benzoyl peroxide	*H*	3.7	650	590 to 750	6	700	680 to 720	4	+8	650	600 to 740	5	0	(d)			
MR-17-B1	do	*H*	3.2	700	670 to 770	6	700	670 to 750	4	0	730	690 to 780	5	+4	(d)			
CR-39	5% benzoyl peroxide	*H*	3.9	870	660 to 960	6	830	710 to 900	3	−5	920	870 to 930	3	+6	(d)			

[a] Six specimens were tested in each case; those which broke in tension were not included in computing the shear strength.
[b] Panels delaminated during exposure on roof.
[c] Panels exposed for only 6 months.
[d] All specimens broke in tension rather than shear.

TABLE 7.—*Effect of catalysts and* pH *on the delamination of resin-bonded birch plywood*

Commercial designation of resin	Catalyst added to resin	Classification	pH of unaged panel	Condition of specimen after delamination test[a]			
				Unaged panel	Over-aged panel	Oven-fog-aged panel	Roof-aged panel
UREA-FORMALDEHYDE RESINS							
Uformite 430	10% ammonium chloride	*R*	1.9				
Do.	10% "Z"	*R*	2.0	D (1)	D (2)	D (1)	DR
Do.	10% "Y"	*R*	2.4	D (1)	D (2)	D (2)	DR
Plaskon 201-2	2% "A"	*R*	3.2	D (3)	D (4)	D (3)	D (1)
Casco 5	5% "AA"	*R*	3.4	D (2)	D (2)	D (2)	DR
Plaskon 250-2	Incorporated with resin	*R*	3.6	D (2)	D (4)	D (2)	D (1)
Plaskon 107	7% B-7	*H*	3.8	D (3)	D (4)	D (3)	D (1)
Uformite 500	None	*H*	5.5	ND; F (5)	ND; F (5)	ND; F (5)	D (5)
Casco 5	do	*H*	5.7	SD (1); F (5)	D (1)	D (1)	D (1)
Uformite 430	do	*H*	4.6	SD (1); F (5)	SD (1); F (5)	SD (1); F (5)	D (5)
UREA-RESORCINOL-FORMALDEHYDE RESINS							
Uformite 500	20% Q-107; 0.7% Q-87	*M*	5.1	ND; F (5)	ND; F (5)	ND; F (5)	D (5)
Plaskon 700-2	16% modifier	*M*	4.6	ND; F (5)	ND; F (5)	ND; F (5)	D (5)
PHENOL-FORMALDEHYDE RESINS							
Durez 12041	10% 7422	*M*	1.8	ND; B (5)	ND; B (5)	ND; B (5)	ND; B (5)
Durez 11427	10% 7422	*M*	1.8	ND; B (5)	ND; B (5)	ND; B (5)	ND; B (5)
Catabond 590	11% hydrochloric acid (27.8%)	*M*	1.7	ND; B (5)	ND; B (5)	ND; B (5)	ND; B (5)
Catabond 200-CZ	do	*M*	1.8	ND; B (5)	ND; B (5)	ND; B (5)	ND; B (5)
Bakelite XC-3931	3% XK-2997	*M*	2.7	ND; B (5)	ND; B (5)	ND; B (5)	ND; B (5)
Bakelite XC-11749	45% XK-11753	*R*	3.1	ND; B (5)	ND; B (5)	ND; B (5)	ND; B (5)
Catabond 590	None	*H*	3.6	ND; F (5)	ND; F (5)	ND; F (5)	ND; B (5)
Bakelite XC-3931	do	*H*	4.5	ND; F (5)	ND; F (5)	ND; F (5)	ND; B (5)
Bakelite XC-11749	do	*H*	3.9	ND; F (5)	ND; F (5)	ND; F (5)	ND; B (5)
Catabond 200-CZ	do	*H*	4.6	ND; F (5)	ND; F (5)	ND; F (5)	ND; B (5)
Cascophen LT-67	8% M-18	*M*	6.4	ND; F (5)	ND; F (5)	ND; B (5)	ND; B (5)
Durez 12041	None	*H*	5.0	ND; F (5)	ND; F (5)	ND; F (5)	ND; B (5)
Tego Film	Incorporated with resin	*H*	8.2	---	---	---	---
Amberlite PR-14	do	*H*	8.4	ND; F (5)	ND; F (5)	ND; F (5)	ND; B (5)
RESORCINOL-FORMALDEHYDE RESINS							
Durez 12490	30% formaldehyde (37%)	*R*	4.8	ND; F (5)	ND; F (5)	ND; F (5)	ND; B (5)
Penacolite G-1124	25% G-1124 B	*R*	5.1	ND; F (5); W	ND; F (5); W	ND; F (5); W	ND; B (5); W
PHENOL-RESORCINOL-FORMALDEHYDE RESIN							
Durez 12533	100% 12534 B	*M*	5.1	ND; F (5)	ND; F (5)	ND; F (5)	ND; B (5)
CASEIN GLUE							
Aircraft Joint P Glue	None	*R*	8.4	ND; F (5); W	ND; F (5); W	ND; F (5); W	DR
UNSATURATED POLYESTER RESINS							
Laminac	1% benzoyl peroxide	*H*	3.7	SD (1); F (5)	SD (1); F (5)	SD (1); F (5)	SD (5); F (5)
Do.	1% lauroyl peroxide	*H*	4.0	SD (1); F (5)	SD (1); F (5)	SD (1); F (5)	SD (5); F (5)
MR-17-A2	3% benzoyl peroxide	*H*	3.7	ND; F (5)	ND; F (5)	ND; F (5)	SD (5); F (5)
MR-17-B1	do	*H*	3.2	ND; F (5)	ND; F (5)	ND; F (5)	SD (5); F (5)
CR-39	5% benzoyl peroxide	*H*	3.9	ND; F (5)	ND; F (5)	ND; F (5)	SD (5); F (5)

[a] The specimens were subjected to 5 cycles of immersion in boiling water and drying, described on page 286. Figure in parentheses refers to cycle in which observation was made. Abbreviations are as follows:

D=delaminated.
SD=slightly delaminated.
ND=no delamination.
DR=delaminated during exposure treatment on roof.
W=warped.
B=brittle.
F=flexible.

The failure of the urea-formaldehyde resin-bonded materials in the delamination test is also affected by the pH of the plywood. The critical value in this test appears to be between 3.8 and 4.6 for both the unaged and the aged specimens.

Three of the panels with a low pH delaminated during exposure. This indicates that the loss in strength on roof aging can be attributed to both deterioration of the wood and deterioration of the resin.

(b) Phenolic Resins

An examination of the values in table 8 for the flexural, impact, and shear strengths of the phenolic resin-bonded panels shows that the presence of acid catalyst causes a decrease in these properties in the unaged panels in every case. This decrease was noticed especially with the panels prepared with the Catabond resins 590 and 200CZ, wherein concentrated hydrochloric acid catalysts were used. It is well known that hydrochloric acid has a decidedly deleterious effect on most woods.

No failure of the phenolic resin-bonded composites occurred in the delamination test. The unaged and laboratory aged specimens with pH values of 3.1 or less were brittle in the final flexibility test on the 4-in. mandrel. With one exception, those with pH values of 3.6 or more were flexible throughout this test.

(c) Other Resins

The remaining adhesives tested, which included resorcinol, furane, casein, and unsaturated polyester types, produced panels of pH 3.2 or greater, with the exception of the furane resin panel which had a pH of 2.2. These adhesives did not undergo marked deterioration in strength when subjected to the laboratory aging tests. The pronounced reduction in strength which occurred under roof aging conditions is attributable mainly to deterioration of the uncoated wood. However, the strengths of the roof-aged panels made with these resins were markedly inferior to those of the roof-aged panel made with the best phenol-formaldehyde resins. It is significant that in the roof-aging tests conducted as part of this investigation, only in the case of the casein and some urea-formaldehyde glues had the breakdown at the bond progressed sufficiently to make strength tests on the roof-aged panels impossible.

TABLE 8.—*Effect of catalyst and* pH *on flexural, impact, and shear strengths of resin-bonded birch plywood*

Commercial designation of resin	Catalyst added to resin	pH of unaged panel	Decrease in flexural strength [a]				Decrease in Izod impact strength [a]				Decrease in shear strength [a]			
			Unaged panel	Oven-aged panel	Oven-fog-aged panel	Roof-aged panel	Unaged panel	Oven-aged panel	Oven-fog-aged panel	Roof-aged panel	Unaged panel	Oven-aged panel	Oven-fog-aged panel	Roof aged panel
UREA-FORMALDEHYDE RESINS														
			Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Uformite 430	None	4.6												
	10% "Y"	2.4	30	39	34	(b)	33	50	40	(b)	29	43	(c)	(c)
	10% "Z"	2.0	37	45	47	(b)	33	46	52	(b)	41	49	(c)	(c)
	10% NHCl	1.9	42	51	61	(b)	33	46	48	(b)	73	75	(c)	(c)
Casco 5	None	5.7												
	5% "AA"	3.4	11	27	26	(b)	27	50	32	(b)	(c)	(c)	(c)	(c)
PHENOLIC RESINS														
Catabond 590	None	3.6												
	11% HCl acid (27.8%)	1.7	56	58	57	64	62	79	72	63	(c)	(c)	(c)	(c)
Catabond 200-CZ	None	4.6												
	11% HCl acid (27.8%)	1.8	51	51	61	62	60	68	63	56	(c)	(c)	(c)	(c)
Bakelite XC-11749	None	3.9												
	45% XK-11753	3.1	25	37	41	31	23	36	48	25	48	19	55	(c)
Bakelite XC-3931	None	4.5												
	3% XK-2997	2.7	27	35	53	8	31	59	46	31	(c)	18	(c)	(c)
Durez 12041	None	5.0												
	10% 7422	1.8	21	28	43	46	30	38	41	50	(c)	(c)	(c)	(c)

[a] Decrease in strength for the unaged, oven-aged, oven-fog-aged, and roof-aged panels, respectively, is calculated on the basis of the strength of the unaged, oven-aged, oven-fog-aged, and roof-aged panels, respectively, made without catalyst.

[b] Panels delaminated during exposure on roof.

[c] Panels containing catalyst or reference uncatalyzed panels failed in tension rather than shear.

2. Effect of Acidic and Basic Catalysts on Strength of Plywood

The outstanding feature of the experiments in which various acids and alkalies were added to the resorcinol-formaldehyde and phenol-formaldehyde resins (figs. 1, 2, 3, and 4) was their apparent absorption by the resin. Although relatively large amounts of the catalysts were added to produce resin solutions of low pH, the resin films and plywood panels had pH values considerably higher than those of their respective solutions.

The titration curves show that there is a definite chemical neutralization reaction between the phenolic type resins and acid and alkali, respectively. The amount of acid or acid-generating catalysts added to cure this type of resinous adhesive at room temperatures is generally greater than the neutral equivalent of the resin. As this additional acid is not destroyed or is only loosely bound to the resin, it is fiee to cause deterioration of the materials in the structure.

The flexural strengths of the unaged panels made with the resorcinol-formaldehyde resin (table 9) did not undergo a significant decrease with increasing acidity of the resin solution. However, the oven-fog aging conditions brought about a substantial reduction in stiength which correlated with decrease in pH. Thus, although the pH of the unaged panels in many instances appeared to be beyond the critical acid range, the acid that had been absorbed by the resin was available to bring about deterioration of the panel under the aging conditions (fig. 8). The strong acids, such

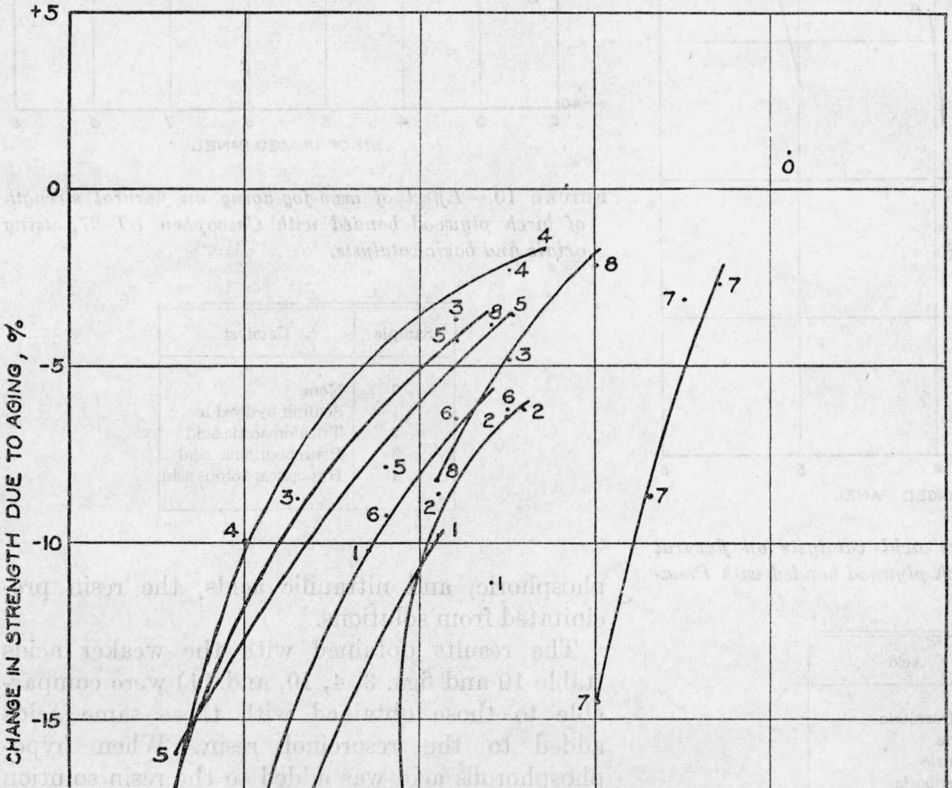

FIGURE 8.—*Effect of oven-fog-aging on flexural strength of birch plywood bonded with Penacolite G-1131, using various acid catalysts.*

Sample	Acid
0	None
1	Hydrochloric
2	Nitric
3	Sulfuric
4	Phosphoric
5	Hypophosphorous
6	Benzenesulfonic
7	Trichloroacetic
8	Nitranilic

as hydrochloric, nitric, and sulfuric acids, had only slightly more deteriorating action than the weaker types, such as nitranilic and hypophosphorous acids (fig. 9).

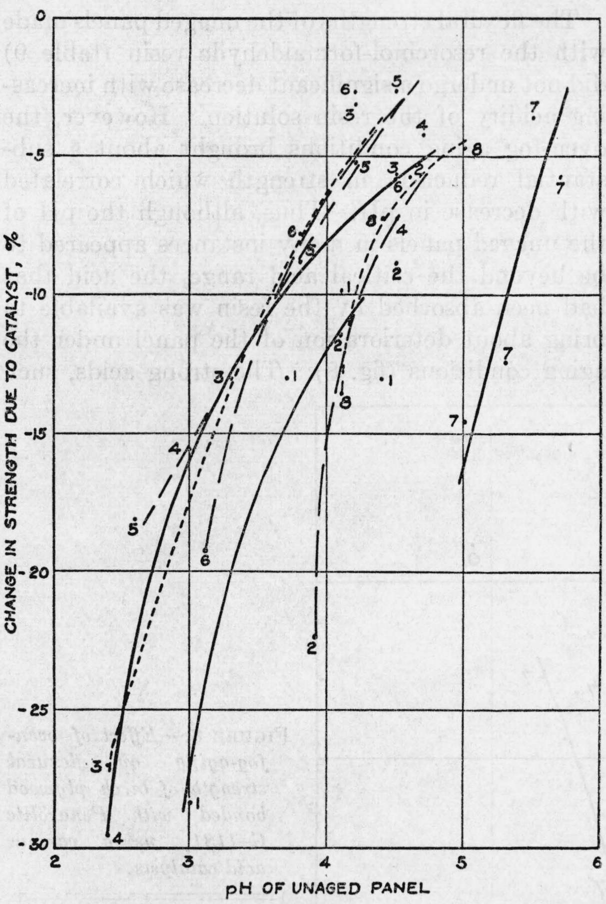

Figure 9.—*Effect of various acid catalysts on flexural strength of oven-fog-aged birch plywood bonded with Penacolite G–1131.*

Sample	Acid
1	Hydrochloric
2	Nitric
3	Sulfuric
4	Phosphoric
5	Hypophosphorous
6	Benzenesulfonic
7	Trichloroacetic
8	Nitranilic

An attempt was made to treat a phenol-formaldehyde resin, Cascophen LT–67, with the same series of acids used in the experiments with the resorcinol-formaldehyde resin. However, in the presence of hydrochloric, nitric, sulfuric, phosphoric, and nitranilic acids, the resin precipitated from solutions.

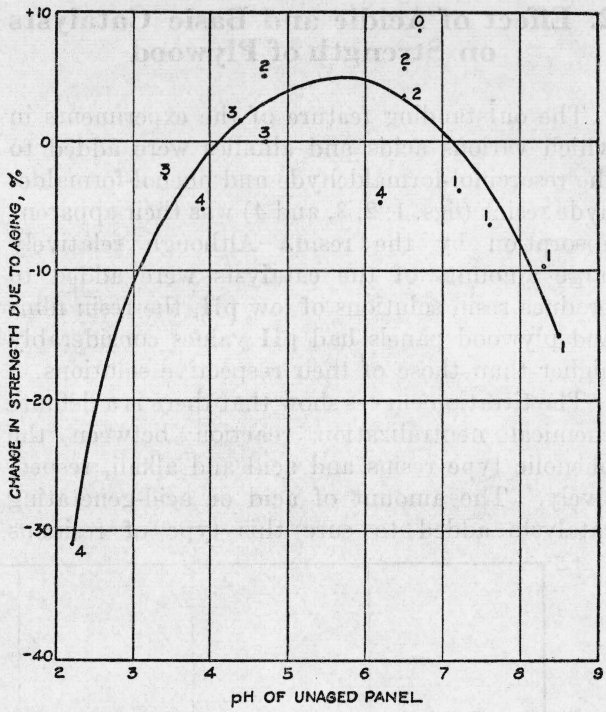

Figure 10.—*Effect of oven-fog-aging on flexural strength of birch plywood bonded with Cascophen LT–67, using acidic and basic catalysts.*

Sample	Catalyst
0	None
1	Sodium hydroxide
2	Trichloroacetic acid
3	Benzenesulfonic acid
4	Hypophosphorous acid

The results obtained with the weaker acids (table 10 and figs. 3, 4, 10, and 11) were comparable to those obtained with these same acids added to the resorcinol resin. When hypophosphorous acid was added to the resin solution in amounts sufficient to lower the pH of the plywood panel prepared with it to 2.2, a considerable decrease in flexural strength occurred in the oven-fog aging tests. A similar effect was observed with another phenol-formaldehyde resin, Durez 12041. It is noteworthy that the flexural strengths of the unaged panels prepared with the phenol-formaldehyde resins were, in general, slightly higher than those of the resorcinol-formaldehyde panels.

TABLE 9.—*Effect of catalyst on flexural strength of birch plywood bonded with a resorcinol-formaldehyde resin, Penacolite G–1131* [a]

Catalyst added to resin	Milliequivalents of catalyst per 100 g of resin	Density of panel	Resin content of panel	pH: Resin solution	pH: Resin film	pH: Unaged panel	pH: Oven-fog-aged panel	pH: Roof-aged panel	Unaged panel: Flexural strength Average	Unaged panel: Flexural strength Range	Unaged panel: No. of specimens	Oven-fog-aged panel: Flexural strength Average	Oven-fog-aged panel: Flexural strength Range	Oven-fog-aged panel: No. of specimens	Roof-aged panels: Flexural strength Average	Roof-aged panels: Flexural strength Range	Roof-aged panels: No. of specimens	Change in strength due to catalyst [b]: Unaged panel	Change in strength due to catalyst [b]: Oven-fog-aged panel	Change in strength due to catalyst [b]: Roof-aged panel	Change in strength due to aging [c]: Oven-fog-aged panel	Change in strength due to aging [c]: Roof-aged panel
		g/cm[3]	*Percent*						*lb/in*[2]	*lb/in*[2]		*lb/in*[2]	*lb/in*[2]		*lb/in*[2]	*lb/in*[2]		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
None	-------	0.93	27.1	7.3	6.5	6.1	5.5	3.7	19,100	17,600 to 20,600	36	19,300	17,900 to 20,500	36	11,100	10,200 to 12,000	36	-----	-----	-----	+1.0	−41.9
Hydrochloric acid	19	.90	22.4	4.1	4.1	4.4	3.9	3.4	18,900	16,900 to 20,600	36	16,800	15,600 to 17,700	36	10,300	9,400 to 11,800	36	−1.0	−13.0	−7.2	−11.1	−45.5
	24	.91	24.0	1.5	2.5	4.1	3.8	3.5	19,300	17,200 to 20,400	36	17,400	15,000 to 18,800	36	10,300	9,000 to 11,500	36	+1.0	−9.8	−7.2	−9.8	−46.6
	32	.89	22.4	0.5	1.8	3.7	3.4	3.4	18,700	17,300 to 19,700	36	16,800	15,100 to 18,700	36	9,900	6,700 to 11,200	36	−2.1	−13.0	−10.8	−10.2	−47.1
	64	.91	23.5	.6	1.3	3.0	3.2	3.2	17,700	15,000 to 20,500	36	13,800	10,100 to 16,200	36	8,200	4,100 to 11,000	60	−7.3	−28.5	−26.6	−22.0	−51.7
Nitric acid	19	.88	21.9	5.3	4.4	4.6	4.3	3.6	19,400	17,500 to 21,200	36	18,200	16,400 to 19,900	36	10,300	8,900 to 12,200	36	+1.6	−5.7	−7.2	−6.2	−46.9
	24	.88	22.3	1.1	2.1	4.5	4.0	3.4	18,800	16,200 to 20,400	36	17,600	16,300 to 18,900	36	9,700	8,400 to 10,600	36	−1.6	−8.8	−12.6	−6.4	−48.4
	32	.90	24.1	0.8	1.7	4.1	3.8	3.5	18,700	17,300 to 21,000	36	17,100	15,100 to 18,200	36	10,000	9,100 to 11,100	36	−2.1	−11.4	−9.9	−8.6	−46.5
	64	.92	24.6	.3	1.5	3.9	3.6	3.4	18,100	12,500 to 20,000	36	15,000	13,700 to 17,200	36	8,600	6,500 to 9,700	36	−5.2	−22.3	−22.5	−17.1	−52.5
Sulfuric acid	19	.91	24.6	4.8	4.3	4.5	4.1	3.1	19,100	17,500 to 21,200	36	18,200	16,300 to 19,700	36	10,000	8,600 to 11,100	36	0.0	−5.7	−9.9	−4.7	−47.6
	24	.88	21.7	2.4	3.1	4.2	4.1	3.2	19,400	17,100 to 22,000	36	18,700	16,500 to 20,000	36	10,200	9,100 to 11,800	36	+1.6	−3.1	−8.1	−3.6	−47.4
	43	.90	23.7	0.9	1.7	3.3	3.1	3.4	18,400	16,100 to 20,400	36	16,800	14,200 to 18,500	36	8,300	7,000 to 9,400	36	−3.7	−13.0	−25.2	−8.7	−54.9
	72	.90	22.5	.4	1.5	2.4	2.5	3.4	18,000	14,200 to 20,400	36	14,100	11,200 to 15,900	36	8,500	6,800 to 10,400	36	−5.8	−26.9	−23.4	−21.7	−52.8
Phosphoric acid	19	.89	23.3	4.8	4.2	4.7	4.2	3.4	18,800	17,000 to 20,800	36	18,500	17,100 to 20,400	36	10,400	9,100 to 11,700	36	−1.6	−4.1	−6.3	−1.6	−44.7
	24	.88	22.7	2.9	3.0	4.5	4.1	3.4	18,300	16,900 to 19,800	36	17,900	15,300 to 19,400	36	10,000	8,100 to 11,200	36	−4.2	−7.2	−9.9	−2.2	−45.4
	51	.90	24.7	1.7	2.0	3.0	2.9	3.2	18,100	16,300 to 19,300	36	16,300	13,500 to 17,900	36	9,700	7,000 to 11,600	36	−5.2	−15.5	−12.6	−9.9	−46.4
	101	.96	28.7	1.1	1.9	2.4	2.5	3.6	18,800	13,800 to 20,400	36	13,600	12,000 to 15,600	36	8,700	7,900 to 9,600	36	−6.8	−29.5	−23.4	−23.6	−51.1
Hypophosphorous acid	20	.87	24.4	3.8	4.0	4.5	4.3	3.5	19,500	16,000 to 21,500	36	18,800	17,100 to 22,000	36	10,900	9,400 to 12,300	36	+2.1	−2.6	−1.8	−3.6	−44.1
	27	.88	24.2	2.4	2.7	4.2	4.1	3.4	19,100	17,900 to 20,100	36	18,300	16,200 to 19,500	36	10,600	9,100 to 12,400	36	0.0	−5.2	−4.5	−4.2	−44.5
	51	.89	24.5	1.7	1.8	3.8	3.5	3.3	19,100	17,600 to 20,500	36	17,600	15,800 to 19,000	36	10,700	8,300 to 12,300	72	.0	−8.8	−4.1	−7.8	−45.5
	100	.91	24.1	1.4	1.6	2.6	2.8	3.5	18,800	17,500 to 20,100	36	15,800	13,900 to 18,200	36	9,000	6,400 to 12,400	35	−1.6	−18.1	−18.9	−16.0	−52.1
Benzenesulfonic acid	19	.86	21.3	4.4	4.2	4.5	4.3	3.1	19,400	18,000 to 20,800	36	18,200	17,100 to 19,500	36	10,200	7,400 to 12,400	36	+1.6	−5.7	−8.1	−6.2	−47.4
	24	.87	22.3	1.3	2.7	4.2	4.1	3.2	20,100	17,900 to 21,300	36	18,800	17,000 to 20,400	36	10,600	9,500 to 12,400	36	+5.2	−2.6	−4.5	−6.5	−47.3
	32	.89	26.6	0.8	1.9	3.8	3.7	3.1	19,600	17,400 to 20,400	36	17,800	14,800 to 19,900	36	9,500	8,200 to 11,300	36	+2.6	−7.8	−14.4	−9.2	−51.5
	64	.90	21.6	.5	1.4	3.1	3.2	3.2	18,900	17,200 to 20,200	36	15,600	13,200 to 17,700	36	9,400	7,200 to 12,100	36	−1.0	−19.2	−15.3	−17.5	−50.3
Trichloroacetic acid	21	.87	20.5	2.8	4.0	5.7	5.0	3.8	18,700	16,900 to 20,500	36	18,200	16,300 to 20,200	36	10,700	9,700 to 11,600	36	−2.1	−5.7	−3.6	−2.7	−42.8
	27	.86	20.4	1.6	2.7	5.5	5.0	3.7	19,200	17,600 to 20,800	36	18,600	17,300 to 20,800	36	10,800	10,200 to 11,600	36	+0.5	−3.6	−2.7	−3.1	−43.8
	43	.85	21.0	1.2	1.6	5.3	5.1	3.7	18,500	15,800 to 20,000	36	16,900	14,900 to 18,800	36	10,300	9,000 to 11,000	36	−3.1	−12.4	−7.2	−8.6	−44.3
	85	.89	21.5	1.0	1.4	5.0	4.7	4.1	19,300	16,700 to 21,100	36	16,500	13,100 to 18,900	36	10,300	9,300 to 11,400	36	+1.0	−14.5	−7.2	−14.5	−46.6
Nitranilic acid	21	.86	21.3	5.5	4.6	5.0	4.5	3.4	18,800	13,800 to 21,100	36	18,400	15,400 to 21,400	36	10,100	9,000 to 11,600	36	−1.6	−4.7	−9.0	−2.1	−46.3
	32	.88	21.8	1.1	3.0	4.4	4.0	3.4	18,600	14,600 to 20,100	36	17,900	15,400 to 20,200	36	10,000	8,600 to 12,000	36	−2.6	−7.2	−10.9	−3.8	−46.2
	45	.87	22.2	0.7	2.7	4.1	3.9	3.3	18,200	16,400 to 20,300	36	16,700	15,200 to 17,700	36	9,300	7,700 to 11,200	34	−4.7	−13.5	−16.2	−8.2	−48.9
Sodium hydroxide	440	1.08	35.3	10.5	11.5	9.2	8.5	-----	19,200	16,900 to 21,500	30	16,000	14,300 to 18,000	30	-----	-----	-----	+0.5	−17.1	-----	−16.7	-----

[a] All panels prepared by pressing at 150° F for 24 hours, using metal bars to control thickness.

[b] Change in strength for the unaged and oven-fog-aged panels, respectively, is calculated on the basis of the strength of the unaged and oven-fog-aged panels, respectively, made without catalyst.

[c] Change in strength calculated on the basis of the strength of the unaged panel.

TABLE 10.—*Effect of alkali and acids on phenolic resin-bonded plywood* [a]

Catalyst added to resin	Milliequivalents of catalyst per 100 g of resin	Density of panel	pH					Flexural strength data									Change in strength due to catalyst [b]			Change in strength due to aging [c]	
			Resin solution	Resin film	Unaged panel	Oven-fog-aged panel	Roof-aged panel	Unaged panels: Flexural strength, Average	Unaged panels: Flexural strength, Range	Unaged panels: No. of specimens	Oven-fog-aged panels: Flexural strength, Average	Oven-fog-aged panels: Flexural strength, Range	Oven-fog-aged panels: No. of specimens	Roof-aged panels: Flexural strength, Average	Roof-aged panels: Flexural strength, Range	Roof-aged panels: No. of specimens	Unaged panel	Oven-fog-aged panel	Roof-aged panel	Oven-fog-aged panel	Roof-aged panel
CASCOPHEN LT-67 AND M-18																					
		g/cm³						*lb/in.²*	*lb/in.²*		*lb/in.²*	*lb/in.²*		*lb/in.²*	*lb/in.²*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
None		0.98	8.5	8.7	6.7	6.4	5.2	22,100	18,700 to 24,000	36	24,000	21,400 to 28,400	36	13,000	11,700 to 15.000	36				+8.6	−41.2
	460	1.03	12.1	12.2	8.6	8.2	5.7	22,100	19,500 to 24,000	36	18,800	17,300 to 20,500	36	13,900	11,900 to 15,200	36	0.0	−21.7	+6.9	−14.9	−37.1
Sodium hydroxide	230	0.95	11.3	11.0	8.3	7.8	6.1	21,800	16,700 to 23,800	36	19,700	17,200 to 21,800	36	14,300	12,400 to 16,300	36	−1.4	−17.9	+10.0	−9.6	−34.4
	105	.98	10.0	10.4	7.6	7.7	5.7	21,800	20,100 to 23,800	36	20,400	17,900 to 21,800	36	13,500	12,000 to 14,700	36	−1.4	−15.0	+3.8	−6.4	−38.1
	33	.97	9.3	10.0	7.2	6.9	5.5	21,300	18,900 to 23,500	36	20,500	19,000 to 22,000	36	12,900	11,800 to 15,500	36	−3.6	−14.6	−0.8	−3.8	−25.4
	41	.94	5.5	5.3	6.5	6.6	4.5	21,000	18,700 to 23,400	36	22,200	18,300 to 24,500	36	12,200	10,900 to 13,900	36	−5.0	−7.5	−6.2	+5.7	−41.9
Trichloracetic acid	49	.92	2.1	4.4	6.5	6.4	5.0	20,200	16,700 to 23,300	36	20,900	18,700 to 23,700	36	11,600	9,400 to 14,400	36	−8.6	−12.9	−10.8	+3.5	−42.6
	64	.89	1.5	1.7	4.7	6.3	4.6	19,500	16,800 to 22,400	36	20,500	18,400 to 22,000	36	12,700	11,100 to 14,000	36	−11.8	−14.6	−2.3	+5.1	−34.9
	39	.92	6.2	5.6	4.7	4.5		21,200	19,000 to 24,900	48	21,200	18,700 to 23,600	42				−4.1	−11.7		0.0	
Benzenesulfonic acid	45	.90	3.1	4.1	4.4	4.2		20,400	18,300 to 23,500	48	20,700	18,500 to 22,800	42				−7.7	−13.8		+1.5	
	61	.87	0.8	2.2	3.4	3.5		17,900	15,300 to 21,400	48	17,400	15,600 to 19,400	42				−19.0	−27.5		−2.8	
	43	1.04	6.4	5.6	4.6	4.0		24,200	20,800 to 26,100	48	22,700	21,300 to 24,800	42				+9.5	−5.4		−6.2	
Hypophosphorous acid	58	1.06	2.7	2.6	3.9	3.6		25,000	22,200 to 28,000	48	23,700	21,300 to 25,900	42				+13.1	−1.2		−5.2	
	116	0.94	1.9	1.6	2.2	2.1		19,700	17,700 to 22,200	48	13,600	11,600 to 14,500	42				−10.9	−43.3		−31.0	
DUREZ 12041																					
None		1.02	7.1	8.1	4.9	4.8		26,800	21,500 to 29,600	48	24,700	20,900 to 27,000	42							−7.8	
	43	0.93	2.1	1.9	3.4	3.4		21,500	18,000 to 24,500	48	19,700	15,900 to 23,200	42				−19.8	−20.2		−8.4	
Hypophosphorous acid	58	1.02	2.3	1.8	3.1	2.5		23,500	20,000 to 26,600	48	22,200	19,000 to 24,400	42				−12.3	−10.1		−5.5	
	116	0.94	1.2	1.3	2.2	2.2		19,400	16,400 to 21,300	48	15,800	13,600 to 19,100	42				−27.6	−36.0		−18.6	

[a] All panels prepared by pressing at 150° F for 24 hours, using metal bars to control thickness.

[b] Change in strength for the unaged, oven-fog-aged, and roof-aged panels, respectively, is calculated on the basis of the strength of the unaged, oven-fog-aged, and roof-aged panels, respectively, made without catalyst.

[c] Change in strength calculated on the basis of the strength of the unaged panel.

The Cascophen LT–67 resin was also treated with various amounts of sodium hydroxide, a strong base. No evidence of significant deterioration in strength of the unaged plywood by relatively large amounts of the alkali was noted. However, there was some decrease in strength when the plywood was exposed to oven-fog aging conditions. The decrease in strength correlated with increase in pH from an initial value of 6.4 for the aged panel without added alkali to 8.2 for the aged panel with the greatest amount of added alkali.

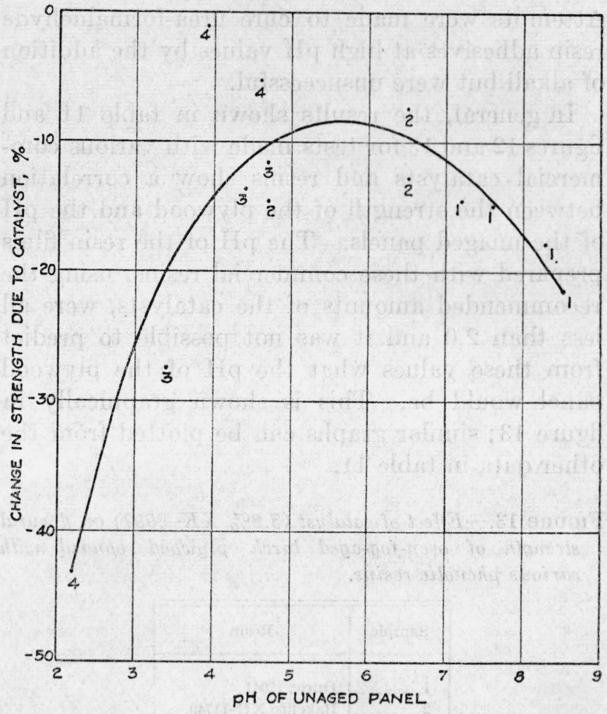

FIGURE 11.—*Effect of various catalysts on flexural strength of oven-fog-aged birch plywood bonded with Cascophen LT–67.*

Sample	Catalyst
1	Sodium hydroxide
2	Trichloroacetic acid
3	Benzenesulfonic acid
4	Hypophosphorous acid

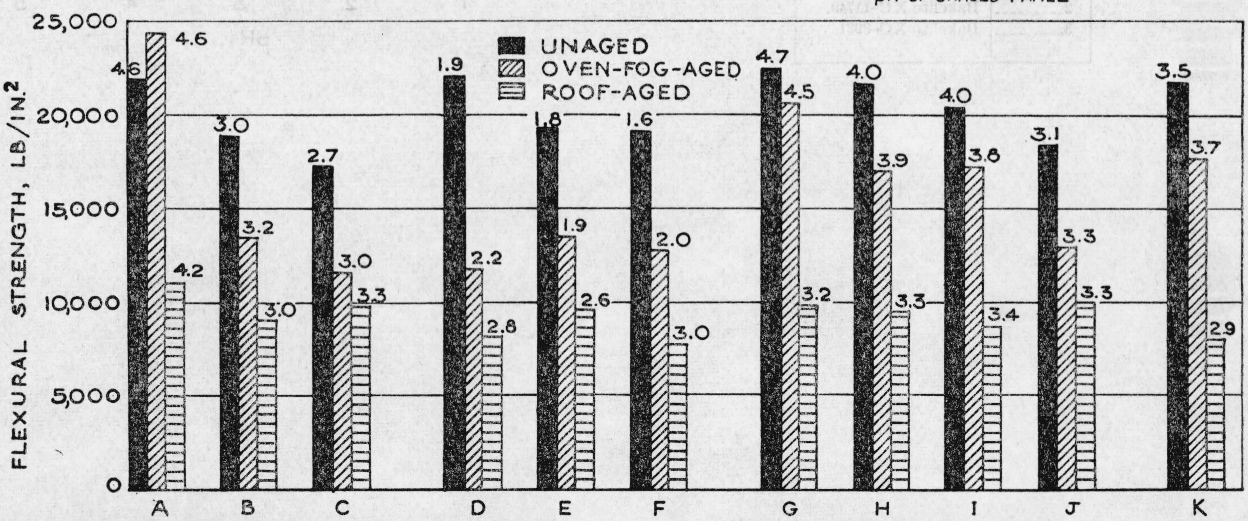

FIGURE 12.—*Effect of various catalysts on flexural strength of birch plywood bonded with phenolic resins.* (*Number above each column indicates* pH *value of unaged panel.*)

Sample	Resin	Catalyst
A	Durez 12041	3.2% Bakelite XK–2997.
B	Bakelite XC–11749	Do.
C	Bakelite XC–3931	Do.
D	Bakelite XC–11749	10% Durez 7422.
E	Durez 12041	Do.
F	Bakelite XC–3931	Do.
G	Bakelite XC–11749	5% Bakelite XK–11753.
H	do	20% Bakelite XK–11753.
I	do	30% Bakelite XK–11753.
J	do	45% Bakelite XK–11753.
K	Bakelite XC–3931	45% Bakelite XK–11753.

Attempts were made to cure urea-formaldehyde resin adhesives at high pH values by the addition of alkali but were unsuccessful.

In general, the results shown in table 11 and figures 12 and 13 for tests made with various commercial catalysts and resins show a correlation between the strength of the plywood and the pH of the unaged panels. The pH of the resin films prepared with these commercial resins, using the recommended amounts of the catalysts, were all less than 2.0 and it was not possible to predict from these values what the pH of the plywood panel would be. This is shown graphically in figure 13; similar graphs can be plotted from the other data in table 11.

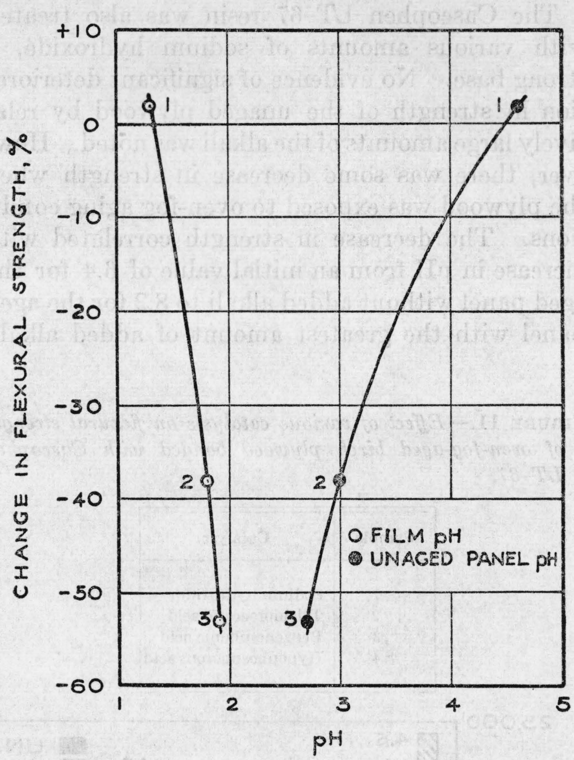

Figure 13.—*Effect of catalyst (3.2% XK–2997) on flexural strength of oven-fog-aged birch plywood bonded with various phenolic resins.*

Sample	Resin
1	Durez 12041.
2	Bakelite XC–11749.
3	Bakelite XC–3931.

TABLE 11.—*The effect of varying resin and catalyst on the flexural strength of phenolic resin-bonded birch plywood*

Commercial designation of resin	Catalyst added to resin	Classification	Conditions of cure: Temperature	Conditions of cure: Time	Density	Resin content	pH: Film	pH: Unaged panel	pH: Oven-fog-aged panel	pH: Roof-aged panel	Unaged panel: Flexural strength: Average	Unaged panel: Flexural strength: Range	Unaged panel: No. of specimens	Oven-fog-aged panel: Flexural strength: Average	Oven-fog-aged panel: Flexural strength: Range	Oven-fog-aged panel: No. of specimens	Roof-aged panel: Flexural strength: Average	Roof-aged panel: Flexural strength: Range	Roof-aged panel: No. of specimens	Change in strength due to catalyst[a]: Unaged panel	Change in strength due to catalyst[a]: Oven-fog-aged panel	Change in strength due to catalyst[a]: Roof-aged panel	Change in strength due to aging[b]: Oven-fog-aged panel	Change in strength due to aging[b]: Roof-aged panel
			°F	*hr:min*	*g/cm³*	*Percent*					*lb/in.²*	*lb/in.²*		*lb/in.²*	*lb/in.²*		*lb/in.²*	*lb/in.²*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Bakelite XC-11749	None	*H*	300	0:45	0.94	26	5.9	4.8	4.4	3.7	24,600	22,100 to 26,800	15	21,900	18,300 to 24,100	15	14,200	11,500 to 16,000	15	-----	-----	-----	−11	−42
	45% XK-11753	*R*	Room	20:00	.88	31	1.9	3.1	3.3	3.3	18,400	15,400 to 19,700	12	12,900	8,700 to 15,300	12	9,800	6,000 to 11,400	12	−25	−41	−31	−30	−47
	3.2% XK-2997	*M*	150	20:00	.94	29	1.8	3.0	3.2	3.0	18,800	15,600 to 23,000	16	13,500	11,600 to 16,400	16	9,000	6,000 to 11,000	16	−24	−38	−37	−28	−52
	10% Durez 7422	*M*	150	20:00	.95	31	1.4	1.9	2.2	2.8	22,100	19,900 to 23,600	16	11,800	9,400 to 13,400	16	8,200	6,500 to 9,100	16	−10	−46	−42	−47	−63
Bakelite XC-3931	None	*H*	300	0:30	.97	35	5.5	4.5	4.5	3.5	23,600	18,100 to 30,000	15	24,800	23,300 to 26,300	15	10,700	9,100 to 12,800	15	-----	-----	-----	+5	−55
	45% XK-11753	*M*	150	20:00	.94	35	1.9	3.5	3.7	2.9	21,800	19,400 to 25,800	16	17,700	14,300 to 20,600	16	8,000	7,100 to 9,800	16	−8	−29	−25	−19	−63
	3.2% XK-2997	*M*	Room 150	20:00 2:00	.90	31	1.9	2.7	3.0	3.3	17,300	15,200 to 19,900	12	11,600	8,800 to 13,600	12	9,800	4,900 to 11,500	12	−27	−53	−8	−33	−43
	10% Durez 7422	*R*	Room	20:00	1.02	43	1.2	1.6	2.0	3.0	18,100	16,700 to 19,200	16	12,800	11,000 to 14,000	16	7,800	6,900 to 9,200	16	−23	−48	−27	−29	−57
Durez 12041[c]	None	*H*	300	0:30	0.97	33	8.2	5.0	5.0	4.7	24,700	22,400 to 28,700	15	23,800	21,300 to 27,100	15	17,800	15,300 to 21,000	15	-----	-----	-----	−4	−29
	3.2% XK-2997	*R*	Room	20:00	1.02	34	1.3	4.6	4.6	4.2	21,800	19,900 to 24,800	16	24,300	18,800 to 27,700	16	11,000	7,300 to 14,500	16	−12	+2	−38	+11	−50
	10% Durez 7422	*M*	150	24:00	0.97	36	1.4	1.8	1.9	2.6	19,400	17,300 to 20,600	12	13,500	10,100 to 15,300	12	9,600	8,400 to 10,900	12	−21	−43	−46	−30	−51
Bakelite XC-11749	None	*H*	300	0:45	.94	26	5.9	4.8	4.4	3.7	24,600	22,100 to 26,800	15	21,900	18,300 to 24,100	15	14,200	11,500 to 16,000	15	-----	-----	-----	−11	−42
	5% XK-11753	*M*	150	20:00	.93	27	4.2	4.7	4.5	3.2	22,600	20,900 to 24,500	16	20,700	17,600 to 22,900	16	9,800	8,700 to 10,800	16	−8	−5	−31	−8	−57
	20% XK-11753	*M*	150	3:00	.89	27	2.3	4.0	3.9	3.3	21,700	18,700 to 24,300	16	17,000	12,700 to 20,100	16	9,400	7,100 to 11,400	16	−12	−22	−34	−22	−57
	30% XK-11753	*M*	150	3:00	.89	27	2.2	4.0	3.8	3.4	20,400	17,300 to 22,800	16	17,200	15,100 to 19,800	16	8,700	7,300 to 9,700	16	−17	−21	−39	−16	−57
	45% XK-11753	*R*	Room	20:00	.88	31	1.9	3.1	3.3	3.3	18,400	15,400 to 19,700	12	12,900	8,700 to 15,300	12	9,800	6,000 to 11,400	12	−25	−41	−31	−30	−47

[a] Change in strength for the unaged, oven-fog-aged, and roof-aged panels, respectively, is calculated on the basis of the strength of the unaged, oven-fog-aged, and roof-aged panels, respectively made without catalyst.

[b] Change in strength calculated on the basis of the strength of the unaged panel.

[c] This resin would not cure with catalyst XK-11753 at 150° F.

3. Effect of Acids and Bases on Wood

The marked decrease in strength of the unaged plywood panels which resulted generally throughout the experiments reported herein when the pH of the panels was lowered by acid catalysts indicated that the wood was being attacked by the acids. The data in table 12 and figure 14 indicate that both pH and catalyst radical have a part in this breakdown. Hydrochloric, benzenesulfonic, nitric, and sulfuric acids had the most pronounced deteriorating effect on the birch wood. Nitranilic and hypophosphorous acids had considerably less deteriorating action on the wood. This is particularly evident from a comparison of strengths for the birch veneers treated with the respective acids to produce pH conditions in the range 2.1 to 2.4.

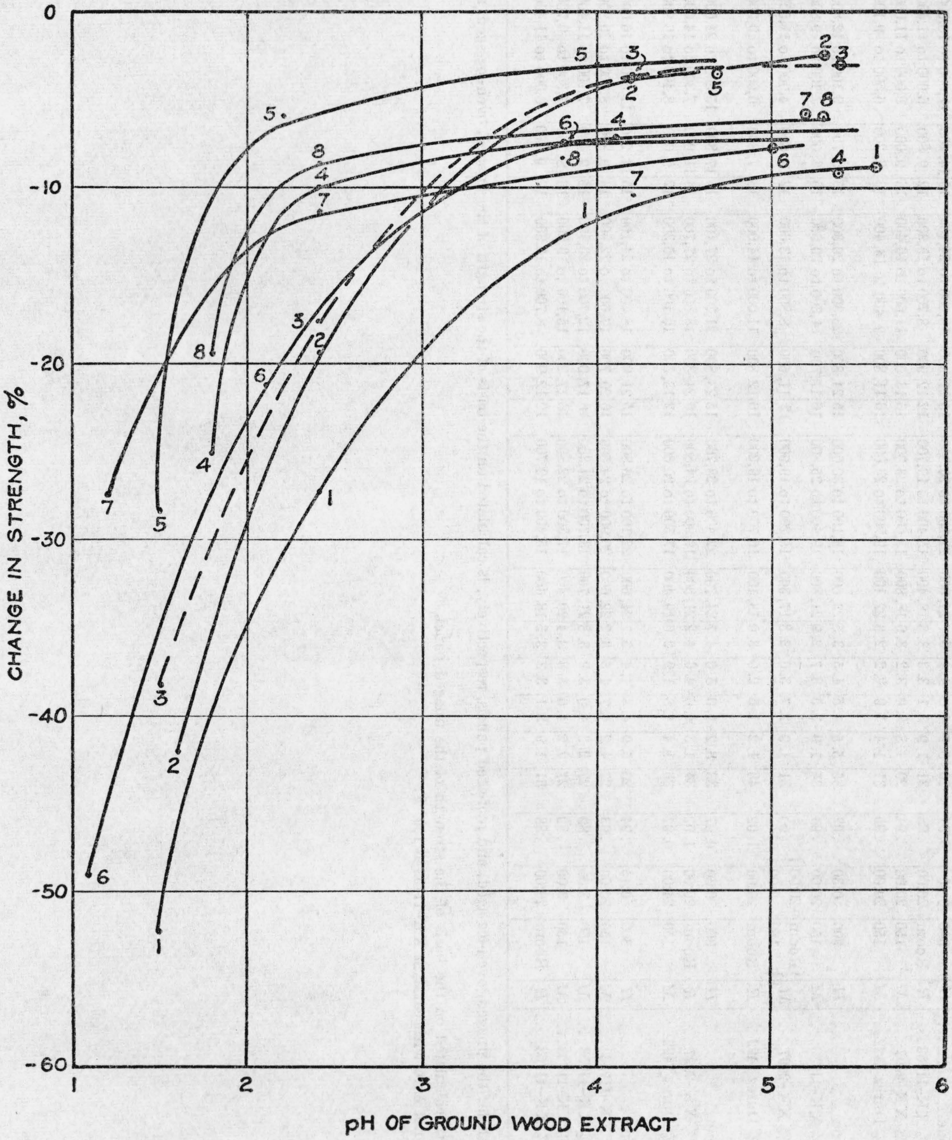

FIGURE 14.—*Effect of various acids on flexural strength of birch wood*

Sample	Acid
0	None (water treated only)
1	Hydrochloric
2	Nitric
3	Sulfuric
4	Phosphoric
5	Hypophosphorous
6	Benzenesulfonic
7	Trichloroacetic
8	Nitranilic

A marked decrease in strength occurred in every case when the pH of the birch veneers was lowered below pH 2.0 by treatment with the respective acids. The wood had a strong buffering action against alkalies. However, a pronounced decrease in strength occurred when the pH of the wood was raised to 8.8 by absorption of tetraethanolammonium hydroxide.

TABLE 12.—*Effect of catalysts on flexural strength of birch veneers* [a]

Catalyst	Normality of solution	pH: Original solution	pH: Solution after wood immersion	pH: Ground wood	Flexural strength: Average	Flexural strength: Range	No. of specimens	Loss in strength [b]
					lb/in.²	*lb/in.²*		*Percent*
Hydrochloric acid	1.0	0.12	0.03	1.5	9,800	8,600 to 12,800	10	52.2
	0.1	1.1	1.4	2.4	14,900	13,000 to 16,500	12	27.3
	.01	2.0	3.1	4.0	18,100	16,800 to 18,900	12	11.7
	Water	5.5	5.2	5.6	18,700	17,100 to 20,000	12	8.8
	Untreated wood [a]			6.0	20,500	19,100 to 22,700	12	
Nitric acid	1.0	0.1	0.21	1.6	12,300	10,800 to 13,800	12	42.0
	0.1	1.1	1.4	2.4	17,100	16,100 to 18,800	12	19.3
	.01	2.0	3.4	4.2	20,400	18,900 to 22,700	12	3.8
	Water	5.5	4.9	5.3	20,700	18,900 to 22,200	12	2.4
	Untreated wood			5.8	21,200	19,100 to 22,900	12	
Sulfuric acid	1.0	0.33	0.34	1.5	12,300	10,700 to 13,400	12	38.2
	0.1	1.3	1.4	2.4	16,400	14,700 to 17,700	12	17.6
	.01	2.1	3.1	4.2	19,200	17,800 to 20,800	12	3.5
	Water	5.6	5.5	5.4	19,300	18,500 to 20,400	12	3.0
	Untreated wood			5.5	19,900	18,900 to 21,600	12	
Phosphoric acid	3.0	0.8	0.88	1.8	15,000	13,900 to 16,700	12	25.0
	0.3	1.6	1.8	2.4	18,000	16,600 to 19,200	12	10.0
	.03	2.2	3.2	4.1	18,600	15,600 to 20,100	12	7.0
	Water	5.5	6.0	5.4	18,500	16,800 to 20,800	12	9.2
	Untreated wood			5.5	20,000	17,600 to 23,400	12	
Hypophosphorous acid	1.0	0.6	0.72	1.5	14,700	12,900 to 16,900	12	28.3
	0.1	1.3	1.6	2.2	19,300	17,400 to 20,400	12	5.9
	.01	2.2	3.1	4.0	19,900	18,900 to 20,700	12	2.9
	Water	5.5	5.2	4.7	19,800	18,100 to 20,300	12	3.4
	Untreated wood			4.9	20,500	19,500 to 21,200	12	
Benzenesulfonic acid	1.0	0.1	0.18	1.1	10,400	9,600 to 11,300	12	49.0
	0.1	1.1	1.2	2.1	16,100	13,900 to 17,800	12	21.1
	.01	2.0	3.2	3.8	18,900	16,900 to 20,400	12	7.4
	Water	5.5	5.4	5.0	18,800	17,300 to 21,000	12	7.8
	Untreated wood			4.9	20,400	18,900 to 22,700	12	
Trichloroacetic acid	1.1	0.1	0.56	1.2	14,000	12,400 to 15,100	12	27.5
	0.11	1.2	1.1	2.4	17,100	15,600 to 19,400	12	11.4
	.01	2.1	2.7	4.2	17,300	15,400 to 19,100	12	10.4
	Water	5.9	5.0	5.2	18,200	16,500 to 20,200	12	5.7
	Untreated wood			5.3	19,300	17,000 to 21,400	12	
Nitranilic acid	1.0	0.42	0.80	1.8	16,600	15,500 to 17,800	12	19.4
	0.2	1.0	1.6	2.4	18,800	18,200 to 19,900	12	8.7
	.02	1.9	2.7	3.8	18,900	18,100 to 20,400	12	8.2
	Water	5.5	5.0	5.3	19,400	17,700 to 20,000	12	5.8
	Untreated wood			5.8	20,600	19,700 to 21,200	12	
Sodium hydroxide	0.1	12.9	10.2	7.0	20,200	18,700 to 22,300	12	6.0
	.01	12.0	6.0	6.2	20,100	17,900 to 22,300	12	6.5
	Water	5.8	5.0	5.4	20,100	18,800 to 21,700	12	6.5
	Untreated wood			5.7	21,500	20,700 to 22,400	12	
Tetraethanolammonium hydroxide	0.44	12.4	11.7	8.8	16,300	12,800 to 17,900	12	20.1
	.22	12.1	8.8	7.1	19,000	17,700 to 21,100	12	6.9
	Water	5.6	5.0	5.1	20,100	18,200 to 21,300	12	1.5
	Untreated wood			5.5	20,400	18,900 to 22,500	12	

[a] A birch veneer of 0.1-in. thickness was cut into the required number of specimens for treatment with a single catalyst. The specimens for immersion in each concentration of the catalyst for 3 days were selected so as to be representative of the whole veneer. Two similar sets of specimens from the same veneer were tested untreated and after immersion in distilled water for 3 days, respectively.

[b] The percentage loss in flexural strength is calculated on the basis of the strength of the untreated wood from the same veneer.

VII. Conclusions

The flexural, impact and shear strengths, both initially and after aging, of urea and phenolic resin-bonded birch plywoods are definitely affected by the pH. In the acid range, the lower the pH of the plywood panel, the poorer is the strength of the panel and its resistance to aging. The lower critical pH value below which optimum strengths are not obtained and deterioration upon aging becomes appreciable, is approximately 4 for urea resin-bonded plywoods and 3.5 for phenolic resin-bonded plywoods. The decrease in strength on aging of birch plywood bonded with a phenolic resin catalyzed with a strong alkali (sodium hydroxide) correlated with increase in pH of the plywood. The upper critical pH values, above which optimum strengths are not obtained and deterioration upon aging becomes appreciable, appears to be in the neighborhood of 8 for phenolic resins; the value for urea resin-bonded plywoods was not established because the resins would not cure at the high pH values.

The delamination of birch plywoods made with urea-formaldehyde resins is affected by the pH; in the acid range, the lower the pH, the fewer cycles required for delamination to occur. The delamination of birch plywoods made with phenolic resin is not affected by the pH; when the pH is less than 3.1, the materials are not as flexible as those with pH values of 3.6 or more. In one-year roof-aging tests delamination occurred only in the case of plywood bonded with casein and with urea-formaldehyde resins containing acid catalysts which reduced the pH of the unaged panel to 3.4 or less.

At a given pH, strong acids, such as hydrochloric, nitric, and sulfuric acids, had only slightly greater deteriorating action on resorcinol-formaldehyde resin-bonded birch plywood than did the weaker types, such as hypophosphorous and nitranilic acids.

The pH values of the birch plywoods made with various resins are not markedly changed by moderate heating (40 hours at 80° C), by exposure to cycles of heat and fog or by exposure outdoors for one year.

Both pH and the nature of the acid radical have an effect on the deterioration of birch wood by acids. At a given pH weak acids have considerably less deteriorating action on the wood than do strong acids. A pronounced decrease in strength of birch wood occurred when the pH of birch wood was raised to 8.8 by absorption of tetraethanolammonium hydroxide.

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